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Survivorship of Introduced Prairie Plant Species in a Degraded Weedy Meadow Under Plant Removal and Non-Plant Removal Conditions

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ABSTRACT

This two-year study addressed the survival of four prairie species, big bluestem (*Andropogon gerardi* Vitman, Poaceae), prairie cord grass (*Spartina pectinata* Link, Poaceae), wild bergamot (*Monarda fistulosa* L., Lamiaceae), and prairie dock (*Silphium terebinthinaceum* Jacq., Asteraceae) planted one meter apart under plant removal and non-plant removal conditions in a degraded weedy meadow. The study site was divided into 1 m^2 plots. Four hundred and thirty-eight seedlings were planted. The plant removal treatment consisted of eliminating visible plant material from an area of 314 cm^2 (radius=10cm) and to a depth of 5 cm for one-half of the total seedlings. Approximately one-half of the plants for each species received the plant removal treatment and one-half received no plant treatment. The seedlings receiving these two different treatments were planted in alternate and adjacent plots. Statistical analyses indicate that there is no significant difference ($p>0.05$) in the planting treatment of the prairie seedlings after the first two growing seasons. It does not appear advantageous to remove adjacent existing weedy plants when planting these four prairie plant species into old field meadows. Planting these prairie plant seedlings directly into weedy old field areas may be advantageous to establish low quality prairie in areas that are small, steeply inclined, or otherwise unsuitable for conventional soil preparation methods such as plowing, discing, and roto-tilling. This planting method can also be used to establish buffer areas surrounding pristine prairie remnants.

INTRODUCTION

Weed competition with prairie plants during the first year following prairie re-establishment is commonly considered to be a major problem. Removal of weeds by tilling beginning at least six months prior to sowing or planting seedlings is the standard obviating method (Schramm 1970 and 1978, Schulenberg,1970). However, prairie re-establishment programs with limited funds, narrow strips of abandoned land, steep embankments, or other small areas often make tilling impractical.

Several non-traditional experimental techniques have been developed as alternatives to the removal of pre-existing plants in prairie enrichment and/or re-establishment projects. Schramm (1978) tried to enrich a prairie restoration with various forb species by cutting holes in existing prairie sod and planting seedlings. Due to grazing by deer and rabbits and competition from existing plants, there was considerable seedling mortality. Warkins and Howell (1983) introduced forb species in established *Andropogon gerardi* and *Sorghastrum nutans* sod at the Fermilab Prairie restoration site using nine different treatments. The most successful treatment was the roto-till/seedling, with the least successful being the sod removal/seedling. Warkins (1988) introduced forb seedlings of five prairie species using roto-till and mow treatments at Fermilab. The results showed little difference between these treatments. At the North Branch Prairie Project, Packard raked prairie seeds into exotic grass turf and, along with fire and time, produced "successional restoration" (Nelson, 1987). Although the above studies have offered alternative methods to large scale tilling in re-establishing and/or enriching a prairie, quantitative analyses of their success are lacking.

This study evaluates the practice of non-plant removal, i.e., planting seedlings of four native prairie species into a weedy old field with scattered recently bulldozed sites. The native prairie plants chosen for re-establishing prairie in this plot were big bluestem (*Andropogon gerardi* Vitman, Poaceae), wild bergamot (*Monarda fistulosa* L., Lamiaceae), prairie dock (*Silphium terebinthinaceum* Jacq., Asteracae), and prairie cord grass (*Spartina pectinata* Link, Poaceae).

SITE LOCATION AND DESCRIPTION OF STUDY AREA

The study site was a weedy old field area on the northeast corner of a marsh located on the campus of College of DuPage. The legal description of College of DuPage property is as follows: SW of NE Quarter, Sections 26 and 27, Township 39, Range 10 in DuPage County, Illinois. The trapezoid-shaped study area is approximately 500 m^2. It is bordered by a thick stand of cattails, *Typha latifolia* L., and *T. angustifolia* L., and sandbar willow, *Salix interior* Rowlee, on the south and west ends. Lawn grass borders the study area on the east and north ends.

Prior to 1965, the study area was farmed. Then between 1965 and 6 June, 1987 the area remained fallow except for some scattered bulldozed scapings from construction activities during 1985. Plant species found in the

study site at the time of seedling transplantation of the four prairie species are listed in Table 1. Soil, chemical, and structural characteristics of the site are given in Table 2.

MATERIALS AND METHODS

A. gerardi, *M. fistulosa*, *S. terebinthinaceum*, and *S. pectinata* were selected for this research because they are common tallgrass prairie natives. The first three species can tolerate degraded/disturbed soils and are among the most hardy prairie plants. *A. gerardi* was the dominant grass of tallgrass prairie that once covered a large part of the Chicago region. It is now restricted to prairie remnants and often is the only prairie species surviving after disturbance of a prairie. *M. fistulosa* and *S. terebinthinaceum* thrive in mesic to hydric prairie but can survive severe degradation (Swink and Wilhelm, 1979). *S. pectinata* was formerly one of the dominant grasses of the tall grass prairie but now survives largely along roadsides, in ditches, and on wet ground (Pohl, 1968).

Seeds for these prairie plants were collected during Fall, 1986, from sources within a radius of 10 miles to ensure local genotypes. All seeds were kept in cold damp storage until 17 February, 1987. They were then stratified with fine damp sand and refrigerated at 4°C in an attempt to duplicate winter conditions.

On 25 March, 1987, the seeds were planted in the College of DuPage greenhouse into a 50-50 mixture of sterilized black soil and "Jiffy Mix Plus" from Ball Seed Company. From 2 May to 20 May, 1987, the seedlings were transplanted to individual jiffy pots and then after one week acclimatized outside in a semi-shaded area. Following acclimatization, the seedlings were transplanted to the study site from 5 June to 12 June, 1987.

The study site was divided into 438 one m^2 plots. Before planting the seedlings, the study site area was mowed to a height of 11 cm, which was the approximate seedling height of the four prairie species. Four hundred and thirty-eight seedlings were planted at a density of one per plot. Seedlings were watered at the time of planting.

The "plant removal" treatment consisted of eliminating visible plant material from an area of 314 cm^2 (radius = 10 cm) and to a depth of 5 cm before transplanting one-half of the seedlings. The remaining one-half were transplanted without removal of any surrounding plant material. Treatments were planted one meter apart in alternate and adjacent plots (Figure 1).

Rainfall data was obtained from the 1987 Climatological Data Annual Survey. The planted seedlings presence was monitored every two weeks from 6 June, 1987 to 30 August, 1987. The seedlings were again monitored on 29 and 30 September, 1988. Seedling survival of *A. gerardi*, *M. fistulosa*, *S. terebinthinaceum*, and *S. pectinata* seedlings between the "plant removal" and "non-plant removal" treatments were compared using the Chi-square analysis of contingency tables (Zar, 1984).

RESULTS AND DISCUSSION

Survivorship of the four prairie species seedlings planted is summarized in Figure 2. Mortalities for all prairie seedlings were greatest during the first two week interval after plantings from 6 June to 20 June, 1987. These early mortalities could be attributed to lower than normal rainfall. When combining both treatment and non-treatment plants, *A. gerardi* had the highest survival (64.3%), followed by *M. fistulosa*, (48.2%), *S. terebinthinaceum* (34.9%), and *S. pectinata* (26.2%).

No significant difference ($p > 0.05$) in seedling survivorship was found between the planting treatments for all species (Table 3). The lack of significance in survivorship suggests that removal of adjacent plant material at least from an area of 314 cm^2 and to a depth of 5 cm when transplanting seedlings of *A. gerardi*, *M. fistulosa, S. terebinthinaceum,* and *S. pectinata* in weedy and degraded old field areas is not necessary.

CONCLUSION

Our study found that *A. gerardi, M. fistulosa, S. terebinthinaceum,* and *S. pectinata* seedlings survive for two years with 26.2 to 64.3% survival when planted directly into a weedy old field area. We found no advantage to removing existing plant material for a circular area of 314 cm^2 and to a depth of 5 cm when planting these seedlings.

Planting prairie seedlings directly into weedy old field areas may be advantageous in establishing low quality prairie in areas which are small, steeply inclined, or otherwise unsuitable for conventional soil preparation methods such as plowing, discing, and roto-tilling. If this technique applies to other species, other applications include enriching existing prairie restoration sites or establishing buffer areas surrounding pristine prairie remnants without causing major soil disturbance.

ACKNOWLEDGEMENTS

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Table 1. Plant species present in old field meadow study area.

The following symbols are used to suggest each plant's role in the context of this specific project (Schulenberg, 1970). Nomenclature is from Swink and Wilhelm (1979).

p = Members of some kind of Chicago-region prairie community. Multiple p's suggest greater fidelity to prairie habitats.

w = weeds, e.g., plants not considered legitimate members of the prairie community. Many of these are true weeds in the sense that they are extremely aggressive in their manner of growth; others are merely "plants out of place." Multiple w's indicate greater aggressiveness and persistence.

Plant's Role	Plant
ww	Abutilon theophrasti, VELVET LEAF
w	Achillea millefolium, YARROW
* www	Agropyron repens, QUACK GRASS
ww	Agrostis alba, REDTOP
ww	Amaranthus retroflexus, ROUGH AMARANTH
* www	Ambrosia artemisiifolia elatior, COMMON RAGWEED
ww	Ambrosia trifida, GIANT RAGWEED
www	Asclepias syriaca, COMMON MILKWEED
p	Aster novae-angliae, NEW ENGLAND ASTER
* www	Aster pilosus, HAIRY ASTER
www	Barbarea vulgaris, YELLOW ROCKET
www	Brassica kaber pinnatifida, CHARLOCK
w	Bromus inermis, HUNGARIAN BROME
w	Chenopodium album, LAMB'S QUARTERS
ww	Cichorium intybus, CHICORY
www	Cirsium arvense, FIELD THISTLE
www	Cirsium vulgare, BULL THISTLE
w	Cornus stolonifera, RED-OSIER DOGWOOD
* www	Daucus carota, WILD CARROT
www	Erigeron annuus, ANNUAL FLEABANE
ww	Erigeron canadensis, HORSEWEED
p	Geum laciniatum trichocarpum, ROUGH AVENS
ww	Hordeum jubatum, SQUIRREL-TAIL GRASS
wwww	Melilotus alba, WHITE SWEET CLOVER
ww	Melilotus officinalis, YELLOW SWEET CLOVER
ww	Phalaris arundinacea, REED CANARY GRASS
www	Phleum pratense, TIMOTHY
w	Plantago major, COMMON PLANTAIN
ww	Plantago rugelii, RED-STALKED PLANTAIN
w	Poa annua, ANNUAL BLUEGRASS
* ww	Poa pratensis, KENTUCKY BLUEGRASS

Table 1. (Continued)

Plant's Role	Plant
www	Polygonum pensylvanicum laevigatum, PENNSYLVANIA KNOTWEED
ww	Rosa multiflora, MULTIFLORA ROSE
w	Rubus occidentalis, BLACK RASPBERRY
www	Rumex crispus, CURLY DOCK
ww	Salix interior, SANDBAR WILLOW
* ww	Setaria faberii, GIANT FOXTAIL
* ww	Setaria glauca, YELLOW FOXTAIL
ww	Setaria viridis, GREEN FOXTAIL
w	Solanum americanum, BLACK NIGHTSHADE
* ww	Solidago altissima, TALL GOLDENROD
www	Sonchus uliginosus, SMOOTH SOW THISTLE
ww	Taraxacum officinale, DANDELION
ww	Trifolium hybridum, ALSIKE CLOVER
ww	Trifolium repens, WHITE CLOVER

* dominant species

Table 2. Site soil characteristics.[1]

Soil pH	7.6		PPM
Organic Matter	5.5%	Zn	91.88
		B	41.00
Kg/ha		Mn	823.00
		Fe	28932
P	6.722	Cu	26.95
K	218.99	Al	29356
		Na	67.1

Cation Percent

P	0.07
K	0.52
Ca	1.03
Mg	0.87
S	0.06

[1]The soil data is a composite of two random samples. It was analyzed by Department of Soil Science, University of Wisconsin Extension, Madison, WI 53705-4364

Table 3. Chi-square analysis of contingency tables for plant removal and non-plant removal treatments for 1987-88. All were nonsignificant ($p>0.05$).

Species	1987	1988	1987-1988
Andropogon gerardi	0.9077	0.0299	0.2032
Monarda fistulosa	1.7199	0.1760	2.3098
Spartina pectinata	0.0050	0.0491	0.2375
Silphium terebinthinaceum	0.8416	0.6054	0.0109

Figure 1. Pattern of alternate and adjacent spacing of plant removal and non-plant removal treatments.

① = *Andropogon gerardi* treatment

② = *Monarda fistulosa* treatment

③ = *Spartina pectinata* treatment

④ = *Silphium terebinthinaceum* treatment

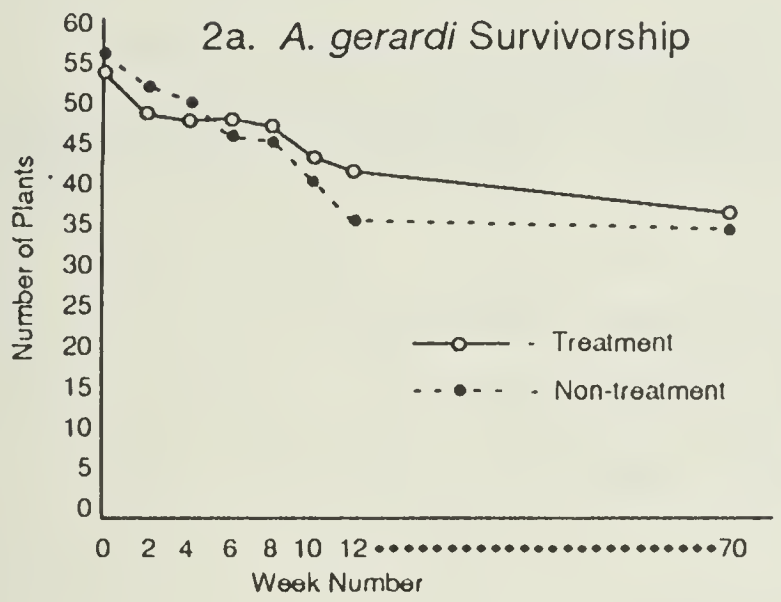
1 = *A. gerardi* non-treatment

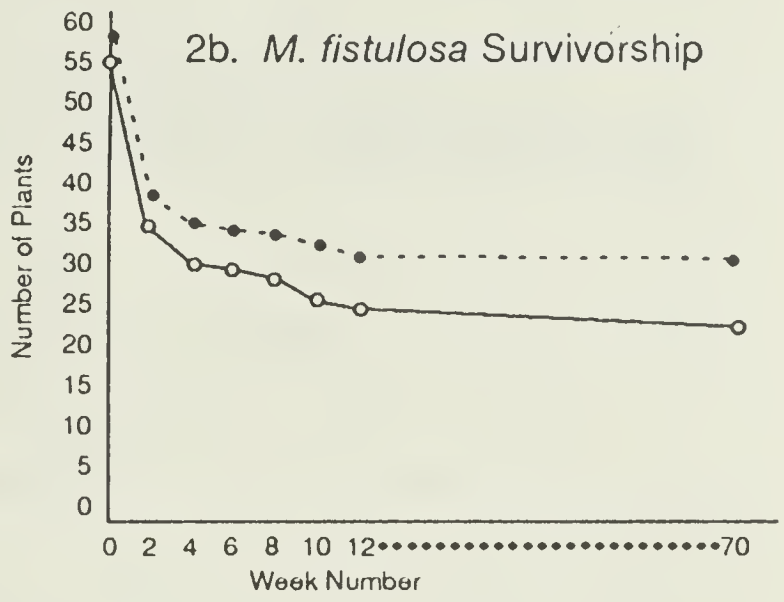
2 = *M. fistulosa* non-treatment

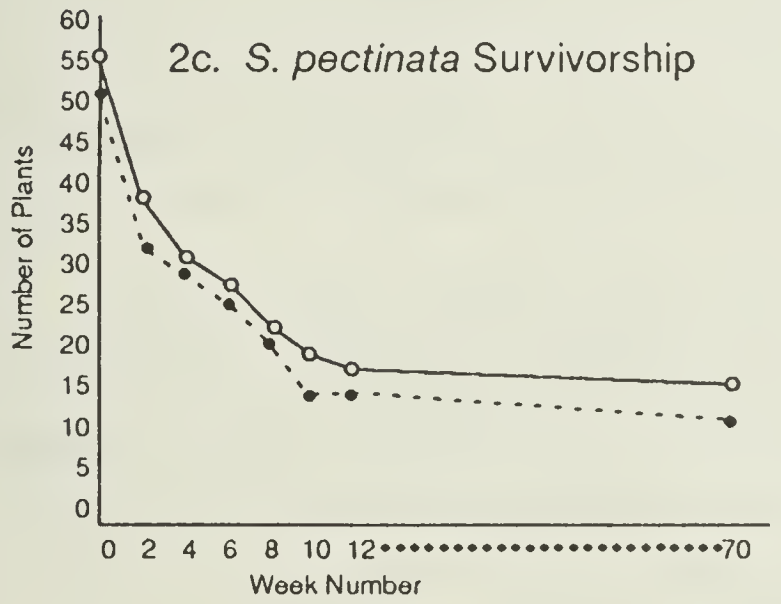
3 = *S. pectinata* non-treatment

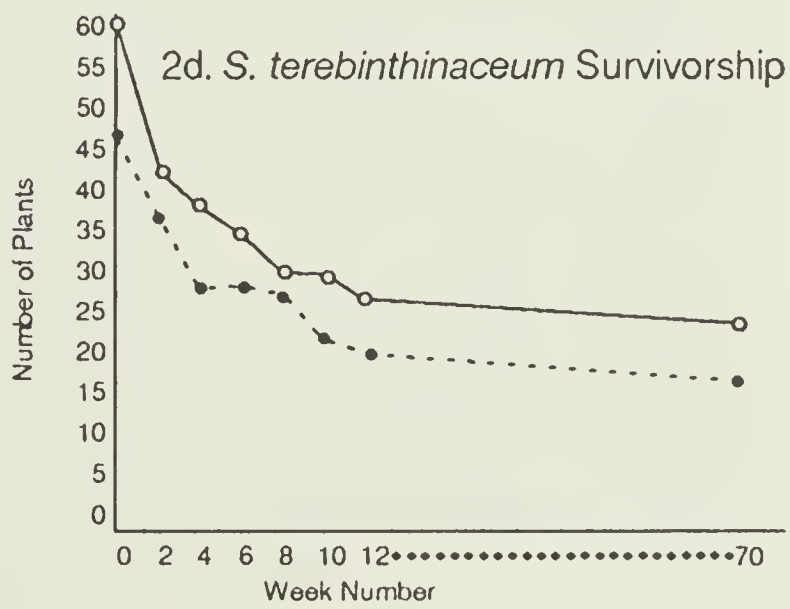
4 = *S. terebinthinaceum* non-treatment

Figure 2. Survivorship of *A. gerardi, M. fistulosa, S. pectinata,* and *S. terebinthinaceum* transplanted seedlings in a degraded weedy meadow from 6 June, 1987 to 30 September, 1988.









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Presettlement Vegetation Of The Mackinaw River Valley, Central Illinois

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ABSTRACT

Government Land Office records were used to determine the presettlement vegetation of a large portion of the Mackinaw River Valley. The vegetation information was placed into four topographic types: flood plain, terrace, slope, and adjacent upland. Within these categories, we distinguished forest and savannah communities from one another based on tree density that was calculated from the witness tree distances. Tree basal area ranged from 14.6 to 42.0 m^2/ha and tree density ranged from 133.6 to 154.4 trees/ha for the forest communities. By comparison, in the savannah, tree basal area ranged from 0.6 to 1.2 m^2/ha and tree density ranged from 2.7 to 5.0 trees/ha. White oak was the most important species of the terrace, slope, and adjacent upland categories, while elm, cottonwood, and sycamore were important species of the flood plain.

INTRODUCTION

In 1784, a commission of the Continental Congress prepared an ordinance for the mode of locating and disposing of the land in the western territory. The plan was established as the Land Ordinance of May 20, 1785. In 1796, work began to survey the lands lying northwest of the Ohio River. Illinois was surveyed during the period 1804 through 1856 (Hutchison, 1988). The area through which the Mackinaw River passes (in what are now the counties of McLean, Woodford, and Tazewell) was surveyed between 1821 and 1833. Most of the work was completed before European settlement had significantly altered the Illinois landscape.

In 1815, a detailed list of "Instructions for Deputy Surveyors" was prepared by E. Tiffin, Surveyor General of the United States. The land was to be divided into squares six miles on a side called Congressional Townships.

Townships were further subdivided into 36 square mile units called "sections." Surveyors were instructed to establish section corners at each mile and quarter section corners at each half mile. From these points, surveyors recorded the courses and distances to the witness or bearing trees. The first witness tree was the closest tree to the corner and a second witness tree was also to be selected, which was opposite to the first tree and adjacent to the corner point. In some instances, only one witness tree was selected and in other cases as many as four trees were chosen. The common name and the estimated diameter of each bearing tree was also recorded. In treeless areas, mounds were raised and posts set to mark corners. At the end of each mile, surveyors also wrote general comments about the character of the land, vegetation, and soil. They also noted natural features that intercepted the survey lines. When streams were encountered, the length, width, and course of the streams were recorded.

Many ecologists believe that the early land survey records provide the most reliable and accurate scientific descriptions of presettlement vegetation that are available. The records are useful from a historical point of view and the information can be applied to future conservation efforts involving restoration or establishment of native vegetation.

Original land survey records have proven to be useful in the determination of original vegetation in several previous studies (e.g., Potzger et al, 1956; Anderson, 1970; Anderson and Anderson, 1975; Delcourt, 1976; Moran, 1978; Rodgers and Anderson, 1979; Leitner and Jackson, 1981; Grimm, 1984; and others). Survey records have also been used to compare presettlement vegetation with present vegetation (Thomson and Anderson, 1976).

In this study, original land survey records were used to determine the presettlement vegetation of a large portion of the Mackinaw River Valley in central Illinois. The river originates near Sibley in Ford County and winds westerly 112 miles (180.4 km) through McLean, Woodford and Tazewell Counties before joining the Illinois River southwest of Pekin (Runkle, 1987). The river falls an average of 3.3 feet per mile (1.0 m/km) and its width ranges from 7 to 125 feet (2.1 to 38.1 m) (Stinauer, 1966).

The majority of the Mackinaw River Valley occurs in the Grand Prairie Natural Division of Illinois (Schwegman, 1973). In this division, forests were generally associated with stream valleys and moraines, while prairie dominated the level to gently rolling landscapes. The Mackinaw River crosses the Bloomington and Shelbyville morainic systems and the narrow plain separating them. The width of the river valley varies from about one-fourth mile (.4 km) at the inner part of the Bloomington belt, to nearly a mile (1.6 km) at the Shelbyville moraine (Stinauer, 1966).

MATERIALS AND METHODS

For section and quarter section points occurring within a quarter mile of the Mackinaw River, witness tree data from the Government Land Office surveys were obtained. Using topographic maps, the elevation of each of these locations was noted, and the points were divided into the following topographic

categories: (1) flood plain (location within the same 10 foot (3.1 meters) contour interval as the river), (2) terrace (location within the next higher contour interval), (3) slope (distinguished by a rapid rise in elevation), and (4) adjacent upland (location on adjacent upland near the river). Topographic maps used in this study included the following 7.5 minute quadrangles: Cooksville, Merna, Lexington, Gridley, El Paso, Secor, Eureka, Mackinaw, Morton, Hopedale, Delavan North, South Pekin, and Pekin. (The Sibley and Colfax quadrangles were not used because neither a well-developed river system nor a flood plain exists near the Mackinaw River at these points.)

From witness tree information provided in the notes, tree species (common name), diameters at breast height, distances, and directions from the section or quarter section corners were recorded. Only the shortest witness tree distance, considered to be the Q1 of the quarter method (Cottam and Curtis, 1956), was used for the computation of the square root of the mean area, because no consistent pattern could be established from the location of the second witness tree after the first witness tree was selected (Rodgers and Anderson, 1979).

Using an estimate of tree density at each section and quarter section point, forest was separated from savannah in each vegetation category based on criteria established by (Anderson and Anderson, 1975). Locations with more than 46.9 trees/ha were considered to be in forest. Locations with more than one tree/2.0 ha but less than or equal to 46.9 trees/ha were considered to be in savannah. The terrace category was not subdivided into forest and savannah communities due to the low number of survey locations occurring in the forest community category.

The quarter method was applied to data for the forest and savannah communities within each vegetation category. Density (trees/ha), relative density, dominance (basal area in m^2/ha), relative dominance, frequency, relative frequency, and Importance Values (IV) were calculated for each taxa (Curtis and McIntosh, 1951).

RESULTS

A total of 140 points were recorded within a quarter mile of the Mackinaw River. For 51 of these points, no witness tree data were given. Twelve points were inaccessible to surveyors due to their occurrence in the Mackinaw River, 30 points had no trees near them, no information was given for one point, and the location of 8 survey points could not be determined due to missing or incomplete section lines on topographic map (8 points). Witness tree data was available for 89 points.

Of the 30 points which listed no trees, 19 points occurred in the flood plain category (16 of these were described by surveyors as prairie), 7 points occurred in the terrace category (5 of these were described as prairie), 1 point occurred in the slope category, and 3 points occurred in the adjacent upland category (1 of these was described as prairie).

Seventeen species of trees were identified from the surveyor's notes to help determine the presettlement vegetation of the Mackinaw River Valley (Table

1). Based on the distributions and habitats of these species, the surveyors' identifications appear to be reasonable. For some genera, such as oak, specific distinctions were made, and for others, such as hickory, ash, and elm, they were not.

For two taxa, overcup oak and s. oak, it was impossible to be certain of the particular species to which the surveyors were referring. Overcup oak is not believed to be *Quercus lyrata* because the range of this species does not presently extend to central Illinois (Mohlenbrock, 1986). However, the surveyors may have misidentified yellow chestnut oak, *Quercus prinoides*, as *Q. lyrata*. Yellow chestnut oak has bark which is similar in appearance to *Q. lyrata* bark. Some of the surveys were conducted when the trees would have been in a leafless condition, making proper identification more difficult. Also, yellow chestnut oak occurs in central Illinois but it was not listed as a witness tree by the surveyors. It is unknown what particular species surveyors were referring to when they noted "s. oak." Shingle oak (*Quercus imbricaria*) or swamp white oak (*Q. bicolor*), both of which occur in moist soil along streams, are possibilities.

The number of tree species was greater on the flood plain (15) than on the upland (4), slope (6), or terrace (7). This was partially the result of more points occurring on the flood plain than in the other communities (Table 2). However, when the average number of species per sampling point was computed, the flood plain (0.38) still had a greater species richness than the slope (0.25) and the adjacent upland (0.25) but not the terrace (0.70). Computing the number of species per point, however, tends to result in higher values for locations with small numbers of sampling points because the number of new species encountered will decrease as the number of sampling points increase.

COMPARISON OF VEGETATION CATEGORIES AND COMMUNITY TYPES

Flood Plain

Of the 55 survey points that occurred in the flood plain, 29 percent were located in prairie, and 33 and 38 percent occurred in forest and savannah, respectively.

Based on Importance Values, elm spp. and cottonwood were the leading species in the flood plain forest, and sycamore and white oak had the highest IV in the flood plain savannah (Table 3).

Elm spp. and cottonwood had the highest density in the forest, followed by black walnut and silver maple, respectively. For the flood plain savannah, sycamore had the highest density, followed by elm spp. and cottonwood. Silver maple, white oak, and bur oak ranked fourth, all with the same density (Table 4). Sycamore had the highest basal area in the flood plain forest. In the flood plain savannah, white oak had the highest basal area, and sycamore and overcup oak ranked second and third, respectively (Table 5).

Terrace

In the terrace category, white oak had the highest importance value, followed by bur oak and black oak as the second and third ranked species, respectively (Table 3). Bur oak had the highest density in the terrace category, followed by white oak and hickory spp. which had the same value (Table 4). White oak had the highest basal area followed by bur oak and black oak (Table 5).

Slope

White oak had the highest importance value for the forest and savannah of the slope category, with black oak as the second leading species. In the forest, the only other species recorded was sugar maple (Table 3). White oak had the highest density (Table 4) and basal area (Table 5) in the forest and savannah communities, and black oak ranked second in basal area and density in both vegetation categories.

Adjacent Upland

White oak and black oak had the two highest importance values for the forest and the savannah of the adjacent upland category, with black walnut as the third leading species in the forest, and hickory spp. as the third in the savannah (Table 3). As in the slope vegetation, white and black oak were the first and second leading species, respectively, in density (Table 4) and basal area (Table 5) in the adjacent upland category.

DISCUSSION

Based upon the results presented, the presettlement vegetation of the Mackinaw River Valley was a mosaic of forest, savannah, and prairie found on flood plains, terraces, slopes, and adjacent uplands. During presettlement times, forested areas in central Illinois generally occurred on more rugged topography associated with river valleys and glacial moraines. Tallgrass prairie dominated on level to gently rolling landscapes (Anderson, 1970; Rodgers and Anderson, 1979) and our data indicates that prairies also occurred in the flood plains.

Fire is thought to have played a major role in determining the presettlement vegetational patterns in central Illinois. Areas of rugged topography were probably more protected from fire than areas with less topographic relief (Wells, 1970; Rodgers and Anderson, 1979; Grimm, 1984; Anderson and Brown, 1986). This allowed forests to survive along moraines and river valleys. Frequent fires on upland sites apparently restricted sugar maple and perhaps other species, such as elm and ash, to areas of rough topography. In the present study, sugar maple was recorded as a witness tree only in the terrace and slope forests. White oak was the dominant species on the uplands in presettlement times, and it still is the dominant canopy tree on uplands in present -day forests. However, as the result of the cessation of fires associated with settlement by Europeans it is apparently rapidly being replaced by sugar maples

and other shade-tolerant, but fire sensitive, mesophytic tree species (Anderson and Adams 1978, Adams and Anderson 1980, Ebinger 1986).

In this study, white oak was the leading species in all vegetation categories except the flood plain, and black oak was second in importance in the slope and adjacent upland categories. Similarly, Rodgers and Anderson (1979) found white oak to be the most important species (and black oak the second) in savannah and forest in the presettlement vegetation of McLean County, Illinois.

Density per hectare for the forest communities ranged from 133.58 in the flood plain to 154.38 on the slope. This was similar to the 159.8 trees/ha reported by Anderson and Anderson (1975) for the presettlement forests of Williamson County. However, for unglaciated southern Illinois Leitner and Jackson (1981) reported slightly higher tree densities ranging from 175.9 trees/ha to 281.4 trees/ha.

Density was much lower for the savannah communities and terrace category than for the forest communities, ranging from 2.72 trees/ha to 8.23 trees/ha. This is fairly consistent with the Rodgers and Anderson (1979) study of the presettlement vegetation of McLean County in which they reported .25 trees/ha and 5.76 trees/ha in the prairie and savannah categories, respectively.

Basal areas of forest communities ranged from 14.63 (flood plain) to 41.97 m^2/ha (adjacent upland). In a study of the vegetation of the Oakwood Bottoms Greentree Reservoir in southern Illinois, Thomson and Anderson (1976) reported basal areas ranging from 6.1 to 37.0 m^2/ha. However, in present-day forests in Central Illinois, Adams and Anderson (1980) reported basal areas of 45.4 m^2/ha for lowland forests and 33.9 m^2/ha for forest similar to the adjacent upland forests of our study. The low total tree basal area of the presettlement flood plain forest compared to the adjacent upland is the result of a smaller average tree basal area (0.11 m^2/ha) in the flood plain than in the adjacent upland forest (0.28 m^2/ha). The reason for the smaller tree size on flood plains in presettlement times compared to present-day forests is not known.

Elm, cottonwood, black walnut, silver maple, and sycamore were found to be important trees of the flood plain. In a study of the presettlement forests of the unglaciated portion of southern Illinois, Leitner and Jackson (1981), found sycamore, cottonwood, ash, and elm to be dominants of the floodplain forest. The present-day flood plain and wet-mesic forests of central Illinois have elm, cottonwood, black walnut, silver maple, and sycamore as important species (Adams and Anderson, 1980). However, white and black oak, characteristic of uplands today and not flood plains, were also present on the flood plain during the original land surveys. Perhaps, the oaks occurred on the ridges within the flood plain, or it is possible the topographic maps do not adequately define the flood plain.

Red oak, bur oak, and Ohio buckeye were noted only in the terrace and/or the flood plain community. In the present-day forests, red oak is a pioneer on mesic sites (Peet and Loucks, 1977) and its distribution extends into dry-mesic and wet-mesic forests. Bur oak is presently found in bottomland woods, in some mesic forests, and also on dry ridges. Ohio buckeye is presently found in wet-mesic and mesic forests and frequently occurs on terraces above the flood plain (Adams and Anderson, 1980).

Surveyors usually recorded general comments about the landscape at the end of each half mile. Prairie was often referred to as "land level and rich" and "fit for cultivation." Flood plain forest was described as "rich bottom timber" or "low wet bottom" in which walnut, buckeye, cottonwood, maple, bur oak, and elm were encountered. Pawpaw was often listed as an understory species. Where the Mackinaw River flows into the Illinois River, surveyors described the area as "swamp." Some of the land was described as "rich timber" with species such as oak and hickory and with the same species as undergrowth shrubs. Much of the adjacent upland was noted as being "thinly timbered with oak and hickory," "rolling second rate barrens," and "broken, not fit for cultivation." Today, much of this land continues to be uncultivated, and some of it remains as forest. Coupled with witness tree data, such notations provide present day ecologists with information which is useful in determining presettlement vegetation.

Our results suggest limitations in using topographic maps with 10 foot (3.1 m) contour intervals to put section and quarter section points into topographic categories that are related to vegetational patterns. This is especially obvious for the flood plain category, where locations with white and black oak were included in the flood plain. It is also possible that even if the section or quarter section point occurred within the flood plain, the closest trees may have been located on an adjacent slope. A refinement of our procedures would be to determine the contour interval of the witness tree location rather than the location of the section or quarter section point.

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Table 1. Tree species identified by surveyors.

Acer saccharinum L. (maple)
Acer saccharum Marsh. (sugar tree, sugar maple)
Aesculus glabra Willd. (Ohio buckeye)
Carya Nutt. spp. (hickory)
Celtis occidentalis L. (hackberry)
Fraxinus L. spp. (ash)
Juglans nigra L. (black walnut)
Morus rubra L. spp. (mulberry)
Platanus occidentalis L. (sycamore)
Populus deltoides Marsh. (cottonwood, cottontree)
Quercus alba L. (white oak)
Quercus macrocarpa Michx. (bur oak)
Quercus rubra L. (red oak)
Quercus L. spp. (overcup oak*, s. oak)
Quercus velutina Lam. (black oak)
Ulmus L. spp. (elm)

*Overcup as described by the surveyors may be *Quercus prinoides* Willd., and s. oak may be *Q. bicolor* Willd. or *Q. imbricaria* Michx.

Table 2. Information about different vegetation categories of the Mackinaw River Valley

	Flood plain		Terrace	Slope		Adjacent Upland	
	Forest	Savannah		Forest	Savannah	Forest	Savannah
Number of tree species	12	11	7	3	5	3	3
Total number of trees	33	30	16	13	25	16	17
Number of points	18	21	10	8	16	7	9
Density (trees/ha)	133.58	2.70	8.22	154.38	4.98	150.05	4.74
Mean tree basal area (m^2)	0.11	0.22	0.24	0.10	0.17	0.28	0.25
Basal area (m^2/ha)	14.63	0.59	1.93	16.07	0.84	41.97	1.18

Table 3. Importance values for the vegetation of the Mackinaw River Valley

	Flood plain		Terrace	Slope		Adjacent Upland	
	Forest	Savannah		Forest	Savannah	Forest	Savannah
Elm	52.9	41.3	-	-	-	-	-
Cottonwood	45.5	32.4	-	-	-	-	-
Black walnut	38.7	15.7	-	-	-	25.5	-
Silver maple	34.3	30.9	-	-	-	-	-
Sycamore	33.8	49.6	-	-	-	-	-
White oak	29.4	46.8	74.3	189.5	198.5	205.0	180.7
Ash	17.5	8.1	-	-	10.3	-	-
Black oak	11.6	-	48.0	78.8	49.1	69.5	90.0
Ohio buckeye	9.8	8.9	15.9	-	-	-	-
Hickory	9.8	-	42.6	-	20.0	-	29.3
Hackberry	9.1	-	-	-	-	-	-
Mulberry	7.5	-	-	-	-	-	-
Overcup Oak	-	25.0	-	-	22.1	-	-
Bur oak	-	25.0	62.9	-	-	-	-
S. oak	-	16.4	-	-	-	-	-
Sugar maple	-	-	26.7	31.7	-	-	-
Red oak	-	-	29.5	-	-	-	-
TOTAL	299.9	300.1	299.9	300.0	300.0	300.0	300.0

Table 4. Density (trees/ha) for the vegetation of the Mackinaw River Valley

	Flood plain		Terrace	Slope		Adjacent Upland	
	Forest	Savannah		Forest	Savannah	Forest	Savannah
Elm	24.29	0.36	-	-	-	-	-
Cottonwood	24.29	0.36	-	-	-	-	-
Black walnut	20.24	0.18	-	-	-	9.38	-
Silver maple	16.19	0.27	-	-	-	-	-
Sycamore	12.14	0.45	-	-	-	-	-
Ash	8.09	0.09	-	-	0.20	-	-
White oak	8.09	0.27	1.54	95.0	3.18	103.16	2.51
Hackberry	4.05	-	-	-	-	-	-
Ohio buckeye	4.05	0.09	0.51	-	-	-	-
Black oak	4.05	-	1.03	35.64	0.80	37.51	1.67
Mulberry	4.05	-	-	-	-	-	-
Hickory	4.05	-	1.54	-	0.40	-	0.56
Overcup Oak	-	0.18	-	-	0.40	-	-
S. oak	-	0.18	-	-	-	-	-
Bur oak	-	0.27	2.06	-	-	-	-
Sugar maple	-	-	0.51	23.74	-	-	-
Red oak	-	-	1.03	-	-	-	-
TOTAL	133.58	2.70	8.22	154.38	4.98	150.05	4.74

Table 5. Basal area (m^2/ha) for the vegetation of the Mackinaw River Valley

	Flood plain		Terrace	Slope		Adjacent Upland	
	Forest	Savannah		Forest	Savannah	Forest	Savannah
Sycamore	2.44	0.10	-	-	-	-	-
White oak	2.25	0.15	0.59	10.93	0.64	30.48	0.87
Cottonwood	2.25	0.04	-	-	-	-	-
Elm	2.16	0.07	-	-	-	-	-
Silver maple	2.08	0.05	-	-	-	-	-
Black walnut	1.11	0.01	-	-	-	4.27	-
Black oak	0.67	-	0.36	4.13	0.13	7.22	0.28
Ash	0.50	0.005	-	-	0.01	-	-
Ohio buckeye	0.40	0.01	0.03	-	-	-	-
Hickory	0.40	-	0.14	-	0.02	-	0.03
Hackberry	0.30	-	-	-	-	-	-
Mulberry	0.07	-	-	-	-	-	-
Overcup Oak	-	0.09	-	-	0.04	-	-
S. oak	-	0.03	-	-	-	-	-
Bur oak	-	0.04	0.41	-	-	-	-
Sugar maple	-	-	0.23	1.01	-	-	-
Red oak	-	-	0.17	-	-	-	-
TOTAL	14.63	0.59	1.93	16.07	0.84	41.97	1.18

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Lactate Dehydrogenase Activity Changes During Peri-Implantation

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ABSTRACT

The specific activity of lactate dehydrogenase was studied in the reproductive tissues of female ICR mice. The specific activity of the enzyme was determined for the uteri and oviducts of pregnant and pseudopregnant mice on Days 1-5 after ovulation as well as for normally cycling mice. The activity of lactate dehydrogenase in the oviducts was found to increase sharply on Days 2 and 3 of pregnancy but only if the embryos were flushed from the oviducts. In pseudopregnant mice, the specific activity of lactate dehydrogenase did not increase when ova were removed. This suggests that an inhibitor of lactate dehydrogenase activity may be present in the oviduct on Days 2 and 3 of pregnancy. In the uterus, the activity was found to increase on Days 1, 2, and 3 for pregnant mice and Days 2 and 3 for pseudopregnant mice. Lactate dehydrogenase activity in both groups was observed to decrease on Days 4 and 5.

INTRODUCTION

Following ovulation and fertilization, the biochemical factors which govern the transport and viability of the developing embryo are poorly understood. There have been a number of studies which address metabolic energy requirements and energy sources for embryos as well as the enzymes required. Embryos at the 1 to 2 cell stage require pyruvate and lactate as energy sources (Georgiev et al., 1970). Lactate dehydrogenase (LDH) is an enzyme which catalyzes the interconversion of lactate and pyruvate using nicotinamide adenine dinucleotide in the oxidized and reduced forms (NAD/NADH). Since the

substrates of LDH are of prime importance to the early embryo, regulation of their levels by LDH has received considerable attention. Spielmann et al., (1978) reported that embryonic LDH activity increased rapidly at implantation and may involve a release from an inhibitory factor. Other studies, also using electrophoresis, a qualitative technique, showed that LDH is present in mouse reproductive tissues (Rapola and Koskimies, 1967). A quantitative method developed by Reeves and Fimognari (1963) for the activity of LDH was later applied to reproductive tissue. The activity of LDH has been determined in the oviductal flushings of the mouse, rabbit, guinea pig, and rat during their estrous cycles (Gibson and Masters, 1970). Further characterization of the activity of LDH of oviducts was seen when estrous rabbits were given injections of progesterone, estradiol, or testosterone (Georgiev et al., 1970). All three hormones were found to increase the activity of LDH from that normally found in an estrous rabbit. In a similar study done with rat reproductive tissue, the uterus and oviduct both showed an increase in LDH activity several days after a progesterone injection was administered. These findings are of interest since the release of an egg into the oviduct normally coincides with a change in the peak level of circulating progesterone. Studies of LDH activity in pregnant animals have mainly been limited to the periods of mating and implantation. When LDH activity was monitored in the rabbit oviduct before and after mating, it was found to increase within 14 hours after copulation (Varma and Talwar, 1975). Another study compared the activity found in the rat uterus during the normal estrous cycle with that activity measured on Days 4 and 5 of pregnancy (Jelinek and Jelinkova, 1977). These authors report that activity of LDH decreased on Days 4 and 5 when compared with the values obtained for the cycling rat uterus. More recently, the effect of estradiol on LDH activity in the rat uterus has been probed (Holt and Rhe, 1987). Ovariectomized rats used in the study were given injections of estradiol at various concentrations. Of the three uterine cell types tested (surface epithelium, muscle, and stroma), the LDH activity in the surface epithelium cells was the only type affected. In these cells, the enzyme activity increased to a maximum on Day 4 of the estradiol injections. The activity in the other two cell types was found to remain constant. These findings suggest that the control of LDH activity by estradiol is limited to the epithelium of the endometrium. Although several studies have been published, changes in LDH activity which may be modulated by the presence of embryos have not been reported. Therefore, in the present study, we have undertaken a systematic study of LDH activity in mouse oviducts and uteri during the peri-implantation period. Since it is difficult to know the exact time at which an embryo associates, irreversibly with the uterus, peri-implantation may be considered to be that period of time during which the uterus is preparing to receive the embryo and some short, but unspecified time after the actual event. Pregnant and pseuodpregnant animals were compared to estimate regulation of maternal LDH by the embryos.

MATERIALS AND METHODS

Materials

All chemicals were purchased from Sigma Chemical Co. (St. Louis, MO).

Preparation of the Mice

All tissues were obtained from adult (21-24g) female ICR mice (*Mus musculus*) from Harlan Sprague Dawley, Inc. (Indianapolis, IN). For studies with pregnant mice, normally cycling mice were given intraperitoneal (ip) injections of 10 IU of pregnant mare serum gonadotropin (PMSG). After two days, the mice were injected with 5 IU of human chorionic gonadotropin (hCG) and placed with males of proven fertility. Pseudopregnant animals received only the PMSG and hCG as described above. In some experiments pseudopregnant mice were prepared by the same PMSG and hCG treatments before being placed with vasectomised males. In both cases the uteri from these animals increased in size suggesting a progesterone response and indicating that ovulation had occurred. In all cases, the presence of a vaginal plug, indicating mating, was observed. The females were then sacrificed on Days 1 through 5 after the hCG treatment, by cervical dislocation, followed by rapid removal of the oviducts and uterus.

Lactate Dehydrogenase Assays

LDH activity was analyzed spectrophotometrically at 340 nm by the method of Reeves and Fimognari (1963). The units of LDH which catalyzed the oxidation of umoles of NADH per minute were determined by dividing the rate (change in absorbance per minute) by 6.2. The specific activity of LDH was calculated by dividing the umoles of NADH oxidized per minute by the mg of protein in the incubation. For each tissue homogenate assayed, the reaction was performed in both the presence and absence of pyruvate. In all cases, the rate was negligible in the absence of pyruvate.

LDH Oviductal Flushings and Homogenates

Oviducts were collected from cycling mice (at any stage in the cycle) or pregnant and pseudopregnant mice on Days 1-5 after ovulation. For each reproductive state, oviducts were either flushed with buffer prior to homogenization or homogenized directly (as indicated in text). Individual oviducts were flushed with 100 ul of Kreb's Ringer Bicarbonate (KRB) after the pH was adjusted to 7.4 (6.95 g NaCl, 0.35 g KCl, 0.16 g KH_2P0_4, 0.14 g $MgS0_4$, 0.90 g glucose, 2.1 g $NaHC0_3$, and 0.19 g $CaCl_2$ per liter, pH 7.4). Each oviduct was flushed twice to remove the embryos or ova. Each flushing was evaluated microscopically for the presence of embryos or ova from pregnant or pseudopregnant mice respectively. Animals which did not have ova or embryos, as appropriate, were not used in these studies. On Days 4 and 5 of pregnancy or pseudopregnancy, all oviducts were not flushed because any embryos present

were expected to be in the uterus. All oviducts were placed on ice, and a wet weight of each oviduct was determined. The tissue was then placed in 1 ml of Kreb's Ringer bicarbonate buffer on ice and homogenized using a Brinkmann polytron at a setting of 3 for thirty seconds. For the LDH enzyme assay, 200 ul of homogenate from each oviduct were tested.

Uterine Preparation For LDH Assay

For each pregnant, pseudopregnant, or normally cycling animal, a total weight of uterine tissue was obtained after careful dissection from the oviducts. The tissue was then placed in 5 ml of Kreb's Ringer Bicarbonate buffer and homogenized with a Brinkmann polytron at a setting of 4 for two thirty second bursts, cooling on ice between bursts. All uterine homogenates were analysed as above except that only 100 ul of uterine homogenate were used in the assay.

Protein Assay

Protein from oviductal and uterine homogenates was evaluated by the method of Lowry et al., (1951) using bovine serum albumin (BSA) as the standard.

Statistics

Statistics were performed using analysis of variance (ANOVA) followed by Fisher's Least Significant Difference (LSD) test. Data were considered to be significantly different at $p < 0.05$.

RESULTS

The specific activities of LDH in mice oviducts and uteri were determined for the various reproductive states between cycling and embryo implantation. When the procedure was used with fresh oviducal tissue, the absorbance of NADH at 340 nm was found to decrease linearly over time. When the assay was run using frozen tissue, the change in absorbance was minimal (data not shown). From this study, it was concluded that the rest of the research should be conducted with fresh tissue.

The oviducts were obtained from three reproductive states: cycling, pregnant, or pseudopregnant during the period from ovulation to implantation. The LDH specific activities of oviduct homogenates are shown in Table 1. On Day 2 the specific activity of the flushed pregnant mouse oviduct was statistically different ($p < 0.05$) from every other point on the graph. The specific activities of flushed pseudopregnant oviducts were not found to be different from the unflushed pseudopregnant oviducts at the same reproductive stage, so these values were combined for this graph. The Day 3 flushed pregnant oviducts were statistically different ($p < 0.05$) from the Day 1 and 2 flushed pregnant oviducts as well as Day 3 unflushed pregnant oviduct. In the mouse oviduct, the specific activity is the highest on Day 2 after ovulation for pregnant animals and the lowest on Day 4 after ovulation in both the pregnant and pseudopregnant oviducts. In

addition, there was no significant difference in the specific activity of oviducts from pseudopregnant mice receiving PMS and hCG only or PMSG, hCG and mating with vasectomised males (data not shown).

The specific activities of LDH in the mouse uterus are shown in Table 2. In pregnant mice, the specific activity of LDH in the uterus increased significantly from Day 0 to Day 2, then decreased from Day 2 to Day 4. Day 5 was not different from Days 0 or 4. The pseudopregnant animals followed a similar trend, except that the trend is shifted to the right by a day. The specific activity in the uterus of pseudopregnant mice was lowest on Days 0 and 1, increased on Days 2 and 3, then decreased on Day 4. Day 5 was not different from Days 0, 1, or 4. On Days 1 and 3, the specific activities of pregnant uteri were found to be statistically different ($p < 0.05$) from the specific activities found in the same day pseudopregnant uteri.

DISCUSSION

In the mouse oviduct and uterus, LDH was easily detected using individual oviductal or uterine homogenates. In all cases, the SA of unflushed pregnant oviducts were not significantly different from the SA of either flushed or not flushed pseudopregnant oviducts. With or without flushing, the specific activity of LDH in the oviduct did not increase in Day 1 pregnant animals (Table 1). This is in contrast to the findings of Varma et al., (1974) and Varma and Talwar (1975). They found that the specific activity increased in the rabbit oviduct 14 hours after mating. Our data also do not agree with another study, using the mouse oviduct, indicating that the specific activity of LDH increased 48 hours after mating in the isthmus of the oviduct (Nieder and Corder, 1983). We found an elevated LDH activity only after flushing the oviduct on Day 2. Whether this is due to difference in species or differences in the experimental design (natural mating versus hormone stimulated process) can not be determined from our data.

The specific activity of LDH in the mouse oviduct increased significantly on Days 2 and 3 of pregnancy only when the embryos were flushed from the oviduct. In Day 2 and 3 pseudopregnant animals, however, the specific activity did not increase when the ova were flushed from the oviducts. This suggests that the flushing process alone is not responsible for the increase in the specific activity of the enzyme. One possibility for this change in the enzyme activity which is detected is that an enzyme inhibitor, present only in pregnant animals, has been flushed from the oviduct. The inhibitor may be present in the pseuopregnant animal also, but it may not be in an active form. However, our experiments do not allow us to evaluate this possibility.

The inhibitor may originate from a number of sources. The embryo is one possible source of the inhibitor. Since the pseudopregnant animal does not contain a genetically distinct organism, no inhibitor would be present. The maternal system is another possible source of the inhibitor. The inhibitor may be inactive until the animal becomes pregnant, or until the maternal system receives some signal from the embryo. Another possible source of the inhibitor is from the male mouse. Since the pregnant animal has contact with the male, it is possible that the inhibitor originates in the sperm or semen. This possibility,

however, seems less likely since the significant increases are on Days 2 and 3 and not Day 1 of pregnancy. In addition, there were no significant differences in the LDH specific activity in the hormonally induced pseudopregnancy when compared to the females (pseudopregnant) housed with a vasectomised male.

The specific activity of LDH in the mouse uterus increased significantly, relative to normally cycling animals, in pregnant animals on Days 2 and 3, then decreased on Days 4 and 5. This agrees well with data obtained by Jelinek and Jelinkova (1977) in the rat uterus. Another study, by Holt and Rhe (1987), found that the maximum specific activity of LDH in ovarectomized rats, that were given injections of estradiol, occurred on Day 4 in the uterus. In the present study, the highest specific activity in mouse uterus was found on Days 2 and 3 of pseudopregnancy or pregnancy. Sakhuja et al., (1982) reported that the SA of Day 4 pregnant mice uteri was 1.262 activity units/mg protein. The article, however, did not define activity units, so a direct comparison with the present data could not be made. The increase seen in the specific activity of the uteri on Days 2 and 3 coincides with the period that the embryo spends in the oviduct. The specific activity on Day 4 or 5 had returned to a level which was not different from that of the cycling mouse (Day 0). In the pseudopregnant uteri, the specific activity decreased slightly on Day 1, then increased significantly on Days 2 and 3 relative to cycling values. When the pregnant uteri were compared with the pseudopregnant uteri, they were found to be significantly different on Days 1 and 3. However, the importance of this observation is not obvious. Since both pregnant and pseudopregnant uteri respond by increasing the LDH activity, this implies that the ovaries (the corpora lutea which are producing progesterone) are involved in this response. The embryos may have a role in shifting the time frame.

The specific activities of the oviducts, for cycling animals, were higher (approximately 1.5 fold) than the values of the uterine tissues. This trend was also observed by Patterson and Masters (1972) who reported higher LDH activities in rat oviducts than uteri. Since the specific activity of LDH increases in both oviducts and uteri after ovulation, the enzyme clearly is responsive to the reproductive state of the animal. In the oviduct these changes may regulate the pyruvate/lactate levels available for the developing embryo. In the uterus, these changes may reflect a change in carbohydrate utilization by the uterine tissue which is undergoing extensive remodeling to accommodate the new embryo. In both the uterus and the oviduct, the presence of the embryo appears to have a profound effect on the maternal system as judged by specific activity changes in the LDH. This is the first report suggesting a regulatory role for the embryo on maternal LDH activity. Further work is necessary to characterize the mechanism of the event.

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Table 1. Specific activity of LDH in oviductal homogenates.

Reproductive State: Day	Mean ± S.D. (N*) Not Flushed	Flushed
Cycling	0.383 ± 0.067[c,d,e] (7)	
Pregnant		
Day-1	0.457 ± 0.021[c,d,e] (3)	0.317 ± 0.081[a,b,c] (3)
Day-2	0.440 ± 0.046[d,e] (5)	0.594 ± 0.125[f] (9)
Day-3	0.340 ± 0.056[b,c,d] (3)	0 473 ± 0.070[e] (4)
Day-4	0.243 ± 0.012[a,b] (3)	N.D.
Day-5	0.295 ± 0.045[a,b] (4)	N.D.
Pseudopregnant		
Day-1	0.382 ± 0.045[c,d,e] (6)	N.D.
Day-2	0.417 ± 0.099[c,d,e] (7)	N.D.
Day-3	0.392 ± 0.078[c,d,e] (6)	N.D.
Day-4	0.200 ± 0.020[a] (3)	N.D.
Day-5	0.320 ± 0.063[b,c] (3)	N.D.

N.D. Not significantly different from the same day flushed values, therefore values were pooled.

Values with the same letter are not statistically different ($p < 0.05$) by ANOVA followed by Fisher's LSD.

N*=Number of animals.

Table 2. Specific activity of LDH in uterine homogenates.

Reproductive State: Day	Mean ± S.D. (N*)
Cycling	0.247 ± 0.071[a,b]
Pregnant	
Day-1	0.310 ± 0.027[b,c] (3)
Day-2	0.363 ± 0.093[c,d] (3)
Day-3	0.328 ± 0.034[c] (5)
Day-4	0.200 ± 0.010[a] (3)
Day-5	0.230 ± 0.066[a,b] (3)
Pseudopregnant	
Day-1	0.190 ± 0.083[a] (5)
Day-2	0.407 ± 0.070[c,d] (3)
Day-3	0.417 ± 0.046[d] (3)
Day-4	0.210 ± 0.020[a] (3)
Day-5	0.220 ± 0.027[a,b] (3)

Values with the same letter are not statistically different ($p < 0.05$) by ANOVA followed by Fisher's LSD.

N*=Number of animals.

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PC Animation and Scottish Country Dancing

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ABSTRACT

If a picture is worth a thousand words, then we may infer that a picture that moves is worth many thousands of words. This premise is the basis for the graphics project presented here. The paper describes the creation of software written in an advanced BASIC to run on an IBM PC to simulate the formations of 32 bars of a Scottish Country Dance. The software serves as an instructional aid helpful to the beginning dancer. Determining the type of representation to be used on the screen, analyzing the various figures to be simulated, and studying techniques of computer animation were among the many interesting facets of solving the problem.

INTRODUCTION

The problem under consideration is that of producing software for Scottish Country Dance (SCD) instruction. Computer graphics animation is used to produce the patterns executed in SCD. Thus the objective of the project is to demonstrate formations of SCD on the computer screen. These formations are described in the definitive work Milligan (1982). The software is to be written to use available hardware, namely, an IBM PC running an advanced BASIC.

The major problem that was encountered in the graphical representation of SCD was the need for extensive calculation for the circular paths which the figures often take. This was solved for the IBM PC representation by setting up "path arrays" which contain the necessary coordinates for the movement of the figures. Using pointers to the array, as well as offsets, eliminates lengthy calculation time during figure movement. The circle and other formation generation techniques employed were chosen to give students practice in mathematics, notably trigonometry.

The formations advance and retire, lead down the middle and up, circle round - right and left, figure of eight, and cast off one are shown in figure 1. These formations are selected from over thirty which are described in Dr. Milligan's work.

The human eye has a characteristic, called persistence of vision, that underlies the success of all animation devices: the retina of the eye retains the image of an object for a brief instant after the removal of the object. The eye blurs many images into one image if the images are presented in quick succession. The computer has recently joined the many devices that have been used to create the illusion of animated pictures. The techniques of computer animation are interesting.

In computer graphics operations the screen is repainted, usually 25 times per second, from a special area of memory, which may be part of the main RAM or may be separate as in the IBM PC. This area is often called the video map because there is a correspondence between the bytes of the video memory and the pixels on the screen. Whatever is put in the video map by the processor automatically appears on the screen the next time it is repainted. Because the screen is repainted so frequently, animation effects can be produced on it.

For the programmer of animation, two systems are available. The first is paging in which there are two or more video maps. This system requires an enormous amount of RAM. The second involves sprites, a number of hardware areas which accept smaller pictures to be transferred into the display area at any given point in time.

The method for implementation of animation is straightforward. The rules are few. An important consideration is the avoidance of flicker. To avoid flicker, the time that a form appears on the screen should be greater than the time the form is off the screen.

IMPLEMENTATION

Keeping these rules in mind, let us turn to the implementation of animation on the IBM PC using BASICA. While there are no sprites available on the IBM PC, the use of GET and PUT statements enable the use of sprite-like areas of RAM. The GET and PUT statements allow the saving of an image or images. The images can be placed on the screen at changing locations. The GET statement transfers the contents of a rectangular area of the screen into an array. The PUT statement is the companion statement to the GET statement, but is not strictly the reverse. An optional parameter, called action, selects one of five ways in which the image may be placed on the screen. PSET and XOR are the most common of the five ways used in producing animation sequences.

The result of PUT with the PSET option is to copy an image drawn with any combination of the PSET, LINE, CIRCLE, PAINT or DRAW instructions to a new screen location without having to redraw the image. PUT with PSET may be thought of as the reverse of GET. This option is quite useful for certain types of animation.

The exclusive OR, XOR, causes the pixels in the image and the corresponding pixels on the screen to be logically XORed together. This allows us to PUT images against a multicolored background. As the PUT image is

moved, the original background is restored. A distracting flicker may occur when erasing and redrawing figures to be animated. One PUT erases the old image and the next PUT draws the new image. During the interval between the two PUT statements, there is no image on the screen causing flicker. It is therefore important to place the two put statements in the program without any intervening operations. When the PSET option is used, the image is PSET initially and then erased by PSETing a blank image on top of it.

If we are not concerned with what is in the background, the PSET option can be used in an even better way. In order to do this, GET the desired image with a border of the background color wider than the distance the image will move each time it is redrawn. Each time the image is redrawn, the border will erase the previously drawn image automatically. Now there is no separate operation to erase the image. Since the image is always on the screen, the animation produced is relatively smooth and flicker free. Action can be faster because there is no need for a separate statement to erase the previously drawn image. However this technique can only be used with a nonpatterned background.

Programming the formations that use motion in straight lines, for example, advance and retire and lead down the middle and up, is quite straightforward using the techniques that have been described. Programming movement in a circular locus presented a more difficult problem.

An early attempt to program a SCD formation that involved movement in a circle included the following program segment.

```
170     FOR I =  1 TO 360 STEP N
180     FOR J = 1 TO 4
190     AN(J) = ( I + 45 + (J - 1)) * P/180
200      X(J)  = 96 + R * COS(AN(J))
210     Y(J)  = 100 + R * SIN(AN(J))
  .
  .
  .
300     NEXT J
310     NEXT I
```

A large amount of flicker is introduced. The reason for this is the large amount of computational overhead involved in the lines shown. The loop first draws the figures, then the next I iteration erases the figures. This violates the rule that figures should be on the screen for a longer length of time than they are off.

Berger (1984) shows that when a path is known in advance a so-called path look-up table may be used. As paths are known in SCD formations, this method may be utilized. The path is precomputed and the coordinate values stored in a table. Then, whenever the object moves, the look-up table may be accessed to determine the screen coordinates of the object. The principle is that it is quicker to look up a value than to calculate it. Hearn and Baker (1986) present an excellent program for generating points for a circular path and this was adapted for use in a development program. Here is the portion of the program that generates the points around a circle.

```
280     I = 0
```

```
290     XFIRST = XCENTER + RADIUS:
        YFIRST = YCENTER
300     X(I) = XFIRST:   Y(I) = YFIRST
310     I = I + 1
320     FOR ANGLE = DA TO 6.28318 STEP DA
330     X(I) = INT(XCENTER + RADIUS * COS(ANGLE) + .5)
340     Y(I) = INT(YCENTER + RADIUS * SIN(ANGLE) * .8333333 +.5)
350     I = I+1
360     NEXT ANGLE
```

In the preceding lines, the user is prompted to enter the coordinates for the center of the circle, the radius, and the number of points to be plotted around the circular path. The value of 2*pi is divided by the total number of points to be generated to give the size of the angle (DA) in radians which will be used in converting the polar coordinates of the points around the circle into their respective cartesian coordinates. Line 290 fixes the position of the first coordinate. Then the loop in lines 320 through 360, the succeeding points are plotted at DA intervals and stored in the two arrays X and Y. With center (100,100), radius 30, and 60 as the number of points, the look-up table is shown in Table 1.

A program involving circular motion, using the path look-up table follows.

```
100     'PROGRAM: movcirc2
110     ' moves a box around in a circle smoothly
120     XCENTER = 196: YCENTER = 58
130     RADIUS = 32
140     TOTALPOINTS = 48
  .
  .     (calculate path matrix)
  .
260     'initialize screen
270     SCREEN 1,0:COLOR 0,1:KEY OFF: CLS
280     'draw box
290     LINE (10,10)-(17,17),2,BF
300     'save image plus 4 pixels of border
310     DIM BOX1(34): GET (6,6)-(21,21),BOX1
320     CLS
330     CIRCLE (XCENTER, YCENTER), RADIUS,3,,, .8333333
340     ' move square around path
350      'subtraction from corner puts figure on center
360     LOCATE 24,5:  PRINT "Press space bar to move box";
370     FOR I = TO TOTAL POINTS
380     PUT (X(I,-8,Y(I)-8),BOX1,PSET
390     FOR W - : TO 30: NEXT W
400     GOSUB 440
410     NEXT I
420     A$-INKEY$: IF A$ - "" THEN 420
430     SCREEN 0: WIDTH 80: CLS : END
```

```
440     A$=INKEY$:IF A$="" THEN 440
450     RETURN
```

The lines 150 through 250 are the same as in the path array generator program. Now that the path look-up table has been stored, the screen is set to medium resolution graphics mode in line 270. A box is drawn and the image plus 4 pixels of border are saved in lines 280 - 310. A circle representing the path to be traveled is drawn at line 330. Then the user may move the object about this circle using another tool, the subroutine at line 440. This subroutine was found to be most useful in working out the simulation of the dance formations. This "step function" is called at the end of each loop thereby enabling the user to move the object one "frame" at a time. Using this tool, any discrepancies in movement may be observed.

The techniques of using a path array generator for path look-up tables and the step function for examining movement "frame" by "frame" are incorporated into the final project program.

In all of the formations, one iteration of a loop is used to simulate one frame of movement. Following each movement, a wait statement is used which is nothing more than an empty for-next loop, spinning away some time, keeping the image on the screen long enough to impact the eye before moving. The final line of the loop checks to see if the step option has been requested.

Because of space constraints, just one of the circular formations, the Circle Round Right and Left, will be discussed. This formation requires the apparent movement of four figures at one time.

The position of the path was determined using graph paper. A radius of 20 pixels was determined to be a good size for the figure and using an approximately 2 to 3 ratio between radius and number of points to be plotted, 2 was chosen as the number. Note that in all cases a number which is divisible by four has been chosen in order to make the circle easy to segment.

Once again, the path array was printed out, so that the positions in which each figure would start to circle could be ascertained. Using these positions as a goal, the path for each image to travel from the start position was determined. How many steps to take? Just draw the circle on the screen, use the step function, until the position is reached and count!

When each of the formations had been developed, we were ready to assemble the program. Each module was joined to the main shell of the program using the advanced BASIC append file function. The hierarchy chart in figure 2 shows the program organization.

CONCLUSION

The project introduced us to the animation capabilities of the IBM PC. One of the major questions which was raised at the start of this project was whether or not the use of advanced BASIC on the IBM PC would be a suitable tool for implementing the formations as an instructional tool for the beginner to learn Scottish Country Dancing. The completed project shows evidence that this implementation is a workable solution to the problem.

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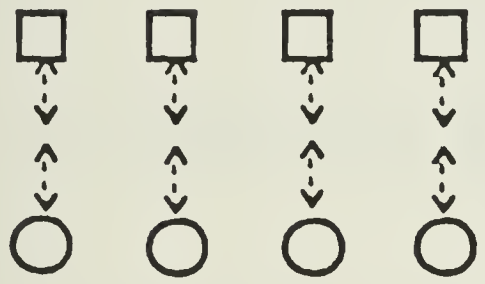
Table 1. A path look-up table.

Center Point: 100 100
Radius: 30
Number Points: 60

	0		1		2	
	x	y	x	y	x	y
0|	130	100	130	103	129	106
6|	124	116	122	118	120	121
12|	109	126	106	127	103	127
18|	91	126	88	125	85	124
24|	76	116	74	114	73	111
30|	70	100	70	97	71	94
36|	76	84	78	82	80	79
42|	91	74	94	73	97	73
48|	109	74	112	75	115	76
54|	124	84	126	86	127	89
60|	130	100	0	0	0	0

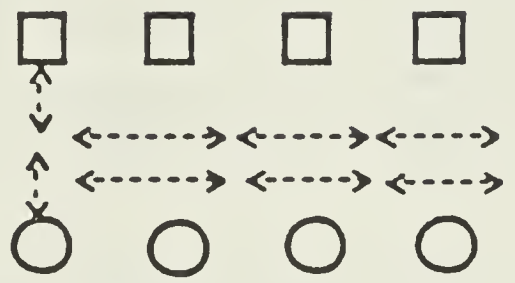
	3		4		5	
	x	y	x	y	x	y
0|	129	109	127	111	126	114
6|	118	122	115	124	112	125
12|	100	128	97	127	94	127
18|	82	122	80	121	78	118
24|	71	109	71	106	70	103
30|	71	91	73	89	74	86
36|	82	78	85	76	88	75
42|	100	72	103	73	106	73
48|	118	78	120	79	122	82
54|	129	91	129	94	130	97
60|	0	0	0	0	0	0

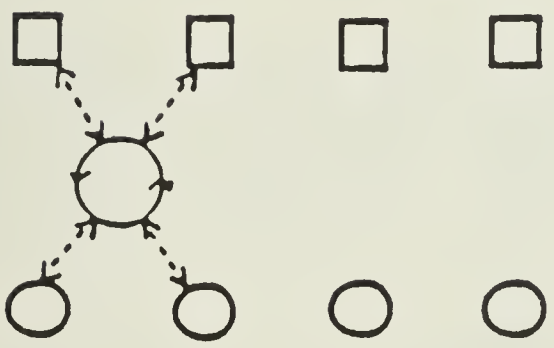
Figure 1. Scottish Country Dance Formations.



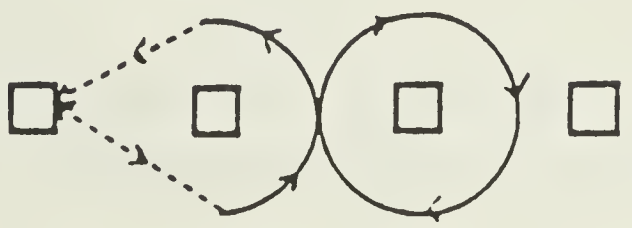
1. Advance and Retire

2. Down the Middle and Up

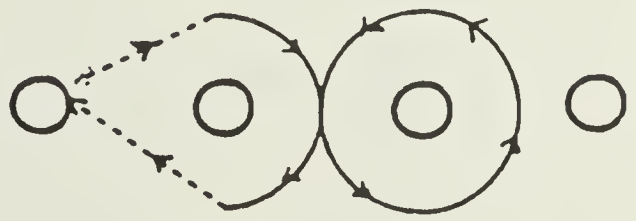


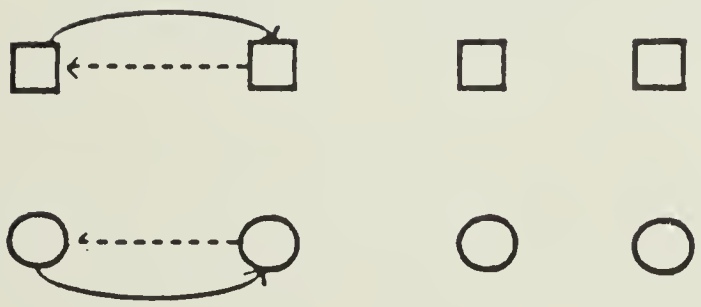


3. Circle Round



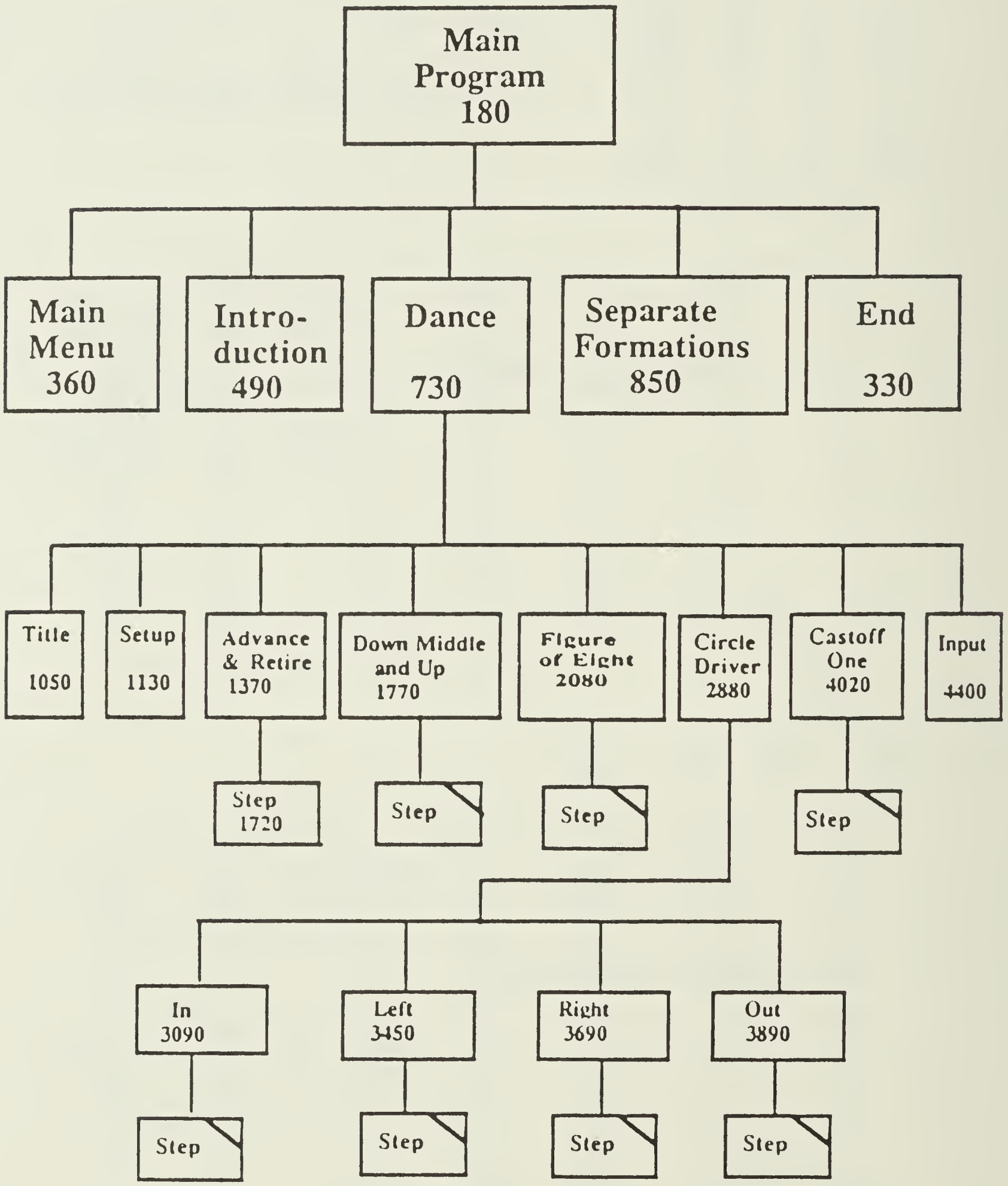
4. Figure of Eight





5. Cast off One

Figure 2. Hierarchy Chart: Scottish Country Dance Formations.



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A History of Weather Observations In Illinois

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Temporal Changes in the Climate of Urbana-Champaign and Illinois

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Use of Cooperative Weather Station Data in Contemporary Climate Research

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PREFACE

A symposium was held on 18 August 1988 at the Illinois State Water Survey in Champaign-Urbana to commemorate the centennial anniversary of continuous weather observations and data collection at that location. This was a particularly significant milestone since the instruments have been located within 2 miles of the original location during the entire 100 year period. The data collected have played a strong role in local agricultural research and in studies of the historical fluctuations of climatic conditions.

The Urbana weather station (so recognized in the official records) was first located adjacent to the present site of Lincoln Hall (1888-1897) on the University of Illinois campus. In 1898, the station was moved 800 feet to the southeast to the College of Agriculture's Morrow Plots, which are the longest active agricultural experimental plots in the nation. There it remained until 1984, when it was relocated 1.6 miles to the southwest to the grounds of the new site of the Illinois State Water Survey, which today affords a representative environment for the station. The University of Illinois maintained the weather station and provided observers from 1888 to 1947, those functions having been assumed by the Illinois State Water Survey since 1948. In 1903, the Urbana station became an official station of the U.S. Weather Bureau (now, the National Weather Service).

The three following papers were presented at the 1988 symposium. They trace the evolution and development of state supported meteorological/climatological observation and research in Illinois, and illustrate the enormous legacy that the Urbana weather station, with its 100 years of data, provide us.

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A History of Weather Observations In Illinois

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INTRODUCTION

The first formal and systematic meteorological observations (as opposed to occasional records in diaries etc.) in the United States were made along the eastern seaboard in the late 1700s. Only several decades later did such observations begin in the central United States. Systematic observations under the auspices of the U. S. Army began in the early 1830s. However, substantial growth awaited several more decades, specifically until the 1870s and 1900, when funding to the Signal Service (which directed the meteorological effort) increased ten-fold. By 1904, there were more than 3,900 reporting weather stations in the U. S.

The number of reporting stations increased rapidly in the late 1800s in Illinois as well, and continues. Figure 1 shows the number of Illinois stations beginning operation in each decade since 1850. The 1880s and 1890s represent the decades with greatest growth in Illinois, with about half of those continuing to the present time. Additional stations were added in the 1940s and 1970s, almost all of which persist to the present time, with about 2/3 reporting precipitation only. Table 1 lists the weather stations in Illinois since 1850, for which daily data are extant, including the first year of operation, whether precipitation, or precipitation and temperature were observed, and whether operation continues to the present. The table was composed by merging data from published National Weather Service and U. S. Army Signal Corps documentation, and from carbon copies of daily observations in the archives of the Illinois State Water Survey. Obviously, other stations may have operated in the state from time to time, but records are no longer extant.

The Smithsonian Institution began to distribute raingages to individuals in exchange for observations by 1853 (Anon., 1855). The first observers in Illinois submitting data to the Smithsonian Institution (Anon., 1855) are presented in Table 2. Unfortunately, the daily observations from these observers are no longer extant.

Meteorological data were published by several and, sometimes, multiple sources during the mid- and late-1800s, including the Smithsonian, and/or some state agency (e.g., the Illinois State Weather Service, Chicago around the turn of the century), and/or privately published sources, e.g., Blodget (1857).

EARLY OBSERVERS AND OBSERVATIONS FROM ILLINOIS

Many of the earliest observing sites continued only for a few years. Six of the cities in Illinois which began observations in the 1870s are no longer cities. Clear Lake (Putnam Co.) became McNabb in 1900; Prairieville (Lee Co.) is now a rural delivery route of Dixon; Irishtown (Clinton CO.) remains only as a township name today; Brush Hill (Tazewell Co.) now only remains as the name of a rural school near Pekin IL; Jordon's Grove (Randolph Co.) disbanded during the 1880s; and Three Mile (Perry CO.), whose population in 1880 was 27, now only remains as the name of a prairie occupying large portions of 2 townships.

The earliest observations in Illinois under the direction of a state or federal agency are from Ft. Dearborn (Chicago), 1832; Albion, 1856; Alton, 1843; Marengo, 1855; Ottawa, 1852; Pekin, 1855; White Hall, 1854; and Woodstock, 1857. Of these, Pekin and Woodstock, no longer function as active weather stations.

Published mean and extreme data from Illinois first appeared in the 1850s. Blodget (1857) published mean temperatures for 7 Illinois sites, Chicago (Ft. Dearborn), data beginning in 1832, Ft. Armstrong (Moline), Ottawa, Augusta, Athens, Ft. Des Moines, and Ft. Dodge. The means were composed of 2 to 12 year's daily data.

The Smithsonian Institution was first to promote and sponsor systematic meteorological observations in the U. S, interestingly, some decades before the efforts of the Mannheim Meteorological Society in Europe during the 1890s, the latter having made great strides distributing instruments and encouraging routine observations at sites around the world. In 1873, the Smithsonian published (Anon., 1873) mean monthly precipitation values for 40 Illinois sites, based on 2 to 20 year's data. In 1876, mean temperature values for 93 Illinois sites appeared (Anon., 1876) the data covering the same general time as those for precipitation. In 1885, mean monthly precipitation data from 78 sites in Illinois (Anon., 1885) were published. Unfortunately, the daily observations for those summaries do not survive.

Eighty-one Illinois weather stations began observing prior to 1900 and continue to the present (listed in Table 1). The earliest of these daily records from Illinois is from Ottawa.

ESTABLISHMENT OF A NATIONAL WEATHER OBSERVING NETWORK

The occasional observations made by individuals in Illinois and elsewhere prior to about 1850 evolved into routine, systematic observations first made under the auspices of the U. S. Dept. of War, when Calhoun was Secretary, the program being under control of the Surgeon General (Maury, 1857). The

directing agency then became the U. S. Dept. of Agriculture, and finally the U. S. Dept. of Commerce.

One of the first to tout systematic observations taken at a common time was Lt. Matthew Fontain Maury (USN). In a 1855 letter to the Editor of the American Farmer, Maury urged farmers to join in systematic weather observing, as he had successfully urged sailors earlier (Maury, 1857). His comments are most perceptive, namely, "We want not only corresponding observations as to the time, but we want them made with instruments that are alike, or that can be compared; with them we may expect to find out something certain and valuable concerning the movements of this grand and beautiful machine, called the atmosphere." (op. cit., p. 488). Not only did he recognize the importance of standard exposures, but also the importance of a common time of observation.

CHANGES IN OBSERVING TACTICS WITH TIME

Prior to the mid 1800s, observations from official sites were usually made at two or more of the following times: 0500, 0600, 0700, 1400, 1700, 1800, and 2100 local time. Temperature, precipitation, snowfall and snow on the ground were typically observed. Mean and extreme daily temperatures could therefore be calculated by a variety of methods. Standard methods for calculating the daily mean included:

$$[T(\text{morning}) + T(\text{evening})] / 2$$
$$[T7 + T14 + T21] / 3, \text{ or}$$
$$[T7 + T14 + T21 + T21] / 4$$

As maximum and minimum thermometers became available, once-per-day observations were possible, having captured the maximum and minimum temperatures.

Because of the numerous ways used to calculate daily means, the homogeneity of temperature records reaching back into the 1800s are suspect until verified. Even if daily means were obtained from maximum/minimum thermometers throughout the time of record, changes in the time of observation must be known to accommodate the time of observation bias (Karl, et al., 1987). Today, once-per-day observations are typically made at 0700, 1700 or midnight (observer choice).

Aside from station relocations and changes in the time of observation, mean monthly temperature data from prior to about the turn of the century to after are likely not homogeneous. Therefore the use of means to determine change or trend over time is questionable. In addition, only after the mid-1880s in the United States was instrument exposure emphasized. At this time Hazen and Aitken strongly argued for proper thermometer exposures, including a radiation screen with ventilation. Prior to that time, thermometers were generally located in an unheated, north-facing room, or hung outside in a (hopefully) shaded location.

OBSERVATIONS AT URBANA

Beginning in 1873, maximum and minimum temperature, 24-hour precipitation, snowfall, wind direction, cloud amount, and "intensity" of storms were recorded by Prof. Burrill, Director of the University of Illinois Experiment Station (Burrill m.s., Univ. of Illinois library). Perusal of these observations shows that January and February of 1875 were very cold indeed, e.g., January`s mean temperature was -10.0°C (current mean: -4.1°C), a value only exceeded 3 times since 1888 (1918, 1977 and 1979). Similarly the February 1875 mean temperature was -9.4°C (current mean: -1.5°C), coldest of any February of record.

Regular, systematic observations on the University of Illinois campus began primarily because of 2 significant occurrences, (1) passage of the Hatch Act in March 1887 (which authorized federal support to establish agricultural experiment stations, and (2) the foresight of the University Trustees, who 6 days after law passage, resolved that the University would establish a weather station.

Changnon & Boyd (1963) report that the Urbana site was first located near the southeast corner of the current Lincoln Hall. In June 1897, the observing site was moved about 200 m to the south southeast, adjacent to Morrow Plots. The site was moved twice more at the Plots, but never more than 20 m from the second location (in April, 1904 and again in June 1948). The initial raingage was essentially the same as one still used today, i.e., a 20.3 cm (8 inch) diameter can. The max/min thermometers were mounted in a louvered wooden shelter. Soil temperature was measured by thermometers placed in glass tubes which penetrated the sod to the appropriate depth.

Station operation was initially under the direction of the Agricultural Experiment Station at the University of Illinois-Urbana. With time, Agronomy Department personnel became interested in the operation of the site, as well as other faculty in the University, notably from the Depts. of Soils, and Geography. In August 1902 the Urbana station became a U.S. Weather Bureau Cooperative Station, a status which continues to today. During the 1930s, interest in the Morrow Plots weather station relaxed somewhat, in part because the University South Farms were growing in use. Indeed, a second observing site was installed at the South Farms under the direction of the Agronomy Dept., the operation of which also continues until today.

The Illinois State Water Survey has supervised the operation of the (now) National Weather Service Cooperative station since May 1948. The site remained at the Morrow Plots until summer of 1984, when it was moved 2.6 km to the Water Survey Research Center. Recording instruments continue to be maintained at the Morrow Plots, and temperature comparisons between the 2 sites will be made after several years of mutual data have been collected.

MEMORABLE WEATHER EVENTS IN EARLY ILLINOIS

The accounts of Andrew Ellicott, of Cairo IL, refer to the severity of the 1796-1797 winter, claiming a minimum temperature of -17.2°C on 22 Dec 1796, still the December record low temperature in Cairo.

Records of early tornadoes in Illinois are sparse. After the Morman community left Nauvoo, a French communal group (Icarians) settled to restore the Morman temple. The temple was totally destroyed by a tornado 27 May 1850 (Ludlum, 1970).

On 13 June 1857, Pana experienced a tornado which destroyed 25 houses, and essentially ruined the remaining buildings in the town from the effects of wind and hail. In another occurrence, nineteen persons were killed, and 50 injured in the Ellison (Warren Co., population: 500) tornado, 31 May 1858.

Ludlum (1968) reports several severe winters and winter storms in Illinois. At times, it is difficult to determine whether the storms were more severe or more frequent than today, or whether the early settlers were simply inexperienced with the severity of Midwestern winters. Regardless, the winter of 1830-31 is now generally known as the Winter of the Deep Snow in Illinois. Records from Ft. Armstrong (Moline) and Ft. Dearborn (Chicago), and those of Dr. Samuel Mead of Augusta IL, a quality observer serving under the direction of the Smithsonian, all indicated cold temperatures for the winter as a whole, and heavy snowfalls of 60 to 90 cm occurring at the end of December. This severe winter with a resulting poor corn harvest in northern Illinois, compelled northern Illinoisans to seek grain in southern Illinois, who had largely escaped the extreme conditions of the north. The furnishing of grain by the south was reminiscent of the Biblical account, leading to the use of the term "Little Egypt" being applied to southern Illinois.

The winter of 1836-37 is known as the Winter of Starving Time in Illinois (Ludlum,1968). In December a strong cold front passed through northern and central Illinois dropping temperatures by more than 22^{o}C in less than 24 hrs. (A temperature change of that intensity in November, today, has a recurrence frequency of about once each 4 years; Wendland, 1987). A man riding a horse from Chatham to Springfield to procure a marriage license began the trip in rain, and arrived in Springfield in snow with temperatures falling rapidly through 0^{o}C. Upon arrival, his great coat was frozen solid, and he was so firmly frozen to the saddle, that he and the saddle were carried into a house and thawed next to the fire. Ft. Dearborn reported a mean December temperature (method of calculation unknown) of -6.7^{o}C (4.2 below the 1951-80 mean), that of January was -5.1^{o}C (+0.8), that of February was -5.6^{o}C (-2.2), and that of March was -2.0^{o}C (-4.1).

The winters of 1855-56 and 1856-57 were also memorable in Illinois. During the former, temperatures at Dubuque IA were less than 0^{o}C for all observations from 21 December through 15 February, 57 days. From 22 December through 11 January, the maximum temperature at Sandwich IL (100 km west of Chicago) never exceeded -17.2^{o}C. The winter of 1856-57 was very cold in the Upper Midwest, with Ft. Ripley MN reporting -45.5^{o}C on 10 February 1857.

THE STATE OF CLIMATOLOGICAL DATA TODAY IN ILLINOIS

The Morrow Plots site continues to be monitored for temperature and precipitation, however a full component of parameters is now continuously measured at the Water Survey Research Center.

About 175 NWS Cooperative stations (shown as a dot on Fig. 2) daily record temperature, precipitation, snowfall and snow on the ground. These data are quality-controlled and published by the National Climatic Data Center (NCDC), Asheville NC. Copies of the original forms are on file at the ISWS, as is the published information from NCDC.

In addition, NWS supports 5 first order stations in the state: O'Hare, Rockford, Moline, Peoria and Springfield (Fig. 2). These sites currently operate 24 hours a day, monitoring virtually all components of the near surface atmosphere; strongly focused on flight operations. Because (1) these site are all located in the northern half of the state, (2) because of the increasing interest in alternative energy sources, and requirements for the specification of parameters other than temperature and precipitation, and (3) because of the Water Survey's commitment to monitor the whole water environment of the state, about 5 years ago the ISWS, supported by the Illinois Dept. of Energy and Natural Resources, installed 17 automatic, recording weather stations in the state, each monitoring temperature, precipitation, pressure, wind, solar, soil temperature and soil moisture (Fig. 2). One need only recall the Water Survey's timely assessments of the 1988 drought to realize only one of the benefits of such a network.

The Water Survey was a pioneer in establishing a means for the dissemination of near real-time climate data to the user public by establishing the Climate Assistance Service (CLASS) in the early 1980s (Changnon et al., 1987). This computer-based system of data and information was widely used by Illinoisans and others to assess the current state of climate and water resources. About half of the users were individuals/farmers, followed by state and federal agency personnel. Principle product requests included (1) pest advisories, (2) weekly forecasts, (3) raw data requests, (4) past 14 day-mean temperatures, and (5) past 14-day total precipitation (Changnon et al., 1987). CLASS provided the foundation for the near real-time regional data and information system operated by the Midwest Climate Center, located at the Illinois State Water Survey.

The Water Survey represents the largest community of meteorologists and climatologists in one location in Illinois, indeed, in most states. Its data, services and research have added much to the understanding of the atmosphere. We are committed to maintain that posture.

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Table 1. Sites of extant daily temperature and/or precipitation observations in Illinois. Beginning year listed. Upper case sites continue to the present. "P" indicates precipitation only observations.

ALBERS P	1964	CARLINVILLE	1891
ALBION	1887	CARLYLE	1898
ALEDO	1888	CARMI	1923
Alexander	1893	Carrollton	1890
Alexis P	1978	CASEY	1887
ALGONQUIN P	1978	Catlin	1890
Altamont	1890	Cazanovia	1890
ALTON	1943	Cedarville	1887
ANNA	1884	CENTRALIA P	1923
ANTIOCH	1901	CHANNAHAN P	1954
APPLE RIVER CANYON P	1985	CHARLESTON	1880
Arlington Heights P	1940	CHEBANSE	1977
Ashland	1887	Chemung	1889
ASHLEY P	1978	CHENOA	1945
Astoria	1899	CHESTER P	1891
Atlanta	1890	CHICAGO *	1859
Atwood	1887	CHILLICOTHE P	1940
AUGUSTA P	1978	Cicero	1933
AURORA	1870	Cisne	1890
AVON P	1950	CLAY CITY P	1946
BARRINGTON	1962	Clear Creek	1894
BEARDSTOWN P	1901	CLINTON P	1910
Beason	1887	Coatsburg	1892
BEECHER CITY P	1962	Cobden	1883
BELLEVILLE	1887	Collinsville	1888
Belvidere	1887	COLMAR P	1965
Bement	1907	CONGERVILLE P	1983
BENTLEY P	1951	Cordova	1890
BENTON	1887	COULTERVILLE P	1978
BLOOMINGTON	1891	CRETE P	1978
Bluffs P	1940	CRYSTAL LAKE	1988
BOURBONAIS	1987	Dakota	1905
BRADFORD P	1980	DANVILLE	1900
BROOKPORT	1926	DAYTON P	1977
BROWNSTOWN	1980	DECATUR	1891
Brush Hill	1888	DE KALB	1881
Bushnell	1890	DES PLAINES P	1983
CAHOKIA	1968	DIONA P	1976
CAIRO	1871	DIX P	1972
Camargo	1888	DIXON	1890
Cambridge	1890	DIXON SPRINGS	1966
CANTON P	1940	DOWNS P	1978
CARBONDALE	1892	DU QUOIN	1887

Dwight	1888
EAST ST. LOUIS P	1910
Eberle	1887
EDWARDSVILLE	1899
EFFINGHAM	1898
ELEROY P	1974
ELGIN	1888
ELIZABETH	1980
ELWOOD	1980
Equality	1898
FAIRBURY	1949
FAIRFIELD	1885
Fairview P	1888
FARMER CITY	1961
FILLMORE P	1962
FLORA	1869
FOX RAPIDS STATE PARK P	1975
Frederick	1890
FREEPORT	1905
Friend Grove	1898
FULTON P	1935
Galatia P	1940
GALENA P	1920
GALESBURG	1895
GALVA	1876
GEBHARD WOODS	1912
GENESEO	1888
GIBSON CITY P	1888
Gilman	1890
GLADSTONE	1936
Glenwood	1890
GLENVIEW P	1983
Golconda	1885
GOLDEN	1889
GRAFTON P	1896
Grand Chain P	1948
GRAND TOWER P	1940
Grayville	1898
GREENFIELD	1949
GREENUP P	1942
GREENVIEW P	1977
GREENVILLE	1878
Gridley P	1940
GRIGGSVILLE	1882
GURNEE P	1978
Halfway	1896
HAMMOND P	1974
HARRISBURG	1888
HAVANA	1870
HENNEPIN	1887
Henry	1888
Herod P	1940
Herrins Prairie	1893
HIGHLAND P	1962
HILLSBORO	1894
Hollidayboro	1894
Holts	1890
HOOPESTON	1887
HOWARD	1973
HUTSONVILLE P	1945
ILLINOIS CITY	1936
INA P	1972
Irishtown	1887
Iron	1890
IUKA	1980
JACKSONVILLE	1887
JERSEYVILLE	1940
JOLIET	1887
Jordan's Grove	1887
KANKAKEE	1887
KASKASKIA	1895
KEITHSBURG P	1931
Kendall	1890
KEWANEE	1939
KILBOURNE	1989
KINCAID P	1972
Kinmundy	1890
Kishwaukee	1888
Knoxville	1895
Lacon	1887
La Grange	1892
LA HARPE	1879
Lake Forest	1887
LAKE VILLA	1985
Lanark	1887
La Salle	1877
LAWRENCEVILLE P	1942
Le Roy P	1936
Lexington	1890
LIBERTYVILLE P	1987
LINCOLN	1888
Loami	1896
LOCKPORT P	1978
Louisville	1890
LOWELL P	1971
MACKINAW P	1940

MACOMB P	1905	Oswego	1887
Mahomet	1887	OTTAWA	1852
MARENGO	1855	PALESTINE	1882
MARIETTA P	1978	PALOKA P	1962
MARION	1895	PANA	1886
MARSEILLES	1941	PARIS	1887
Martinsville	1893	PARK FOREST	1952
Martinton	1887	PAW PAW	1913
Mascoutah	1882	PAXTON	1986
MASON CITY	1961	PAYSON P	1888
MATTOON	1888	Pearl P	1917
MC HENRY P	1940	Pekin	1888
MC LEANSBORO	1882	PEORIA	1855
MEDORA P	1942	PEOTONE P	1940
Melvin	1887	Perry	1887
MINONK	1893	PERU	1945
MOLINE **	1871	PETERSBURG	1889
MOMENCE P	1977	Philo	1887
MONMOUTH	1887	PINKNEYVILLE P	1972
MONTICELLO	1942	PIPER CITY	1912
Morgan Park	1897	PITTSFIELD P	1978
Morris	1911	PLUMFIELD P	1983
MORRISON	1895	Plum Hill	1896
MORRISONVILLE	1899	PONTIAC	1887
Mound City	1887	PRAIRIE DU ROCHER P	1953
MOWEQUA	1962	Prairieville	1887
MT. CARMEL	1887	PRINCETON	1945
MT. CARROLL	1890	PRINCEVILLE	1929
MT. OLIVE P	1930	PROPHETSTOWN P	1978
MT. PULASKI P	1930	QUINCY P	1911
MT. STERLING P	1943	RAMSEY P	1962
MT. VERNON	1894	RANTOUL	1895
MURPHYSBORO P	1978	Raum	1899
NASHVILLE	1901	RED BUD P	1946
Neponset	1887	REND LAKE	1973
New Athens	1887	Reynolds	1896
NEW BOSTON P	1936	Richview	1887
New Burnside	1895	Riley	1859
NEWMAN P	1974	RIPLEY P	1937
NEWTON	1921	RIVERTON P	1975
NOKOMIS P	1978	Roberts P	1911
NORMAL	1893	Robinson	1896
Old DuQuoin	1888	ROCHELLE P	1926
OLIVE BRANCH	1983	ROCK FALLS P	1984
OLNEY	1887	ROCK ISLAND	1935
Oneida	1887	ROCKFORD	1872
Oquawka	1887	Rose Hill	1890
OREGON	1909	ROSICLARE	1942

Round Grove	1897	TUSCOLA	1893
RUSHVILLE	1889	URBANA	1888
SALEM P	1915	UTICA	1941
Savanna	1887	VANDALIA	1887
Scales Mound	1897	VARNA P	1987
Schyler	1890	VIRDEN	1887
SEVILLE P	1983	VIRGINIA P	1962
SHAWNEETOWN P	1910	WALNUT	1891
SHELBYVILLE	1978	WALTONVILLE P	1972
SHIRLAND P	1959	Wapella	1888
Shobonier	1900	Warsaw P	1905
SIDELL P	1945	WASHINGTON P	1978
SKOKIE P	1978	Wataga	1888
SMITHLAND	1980	WATERLOO	1912
SPARLAND P	1987	WATERMAN P	1978
SPARTA	1887	WATSEKA	1887
SPRINGFIELD	1877	WAUKEGAN	1923
St. Charles	1890	Waverly P	1935
St. John	1883	WAYNE CITY P	1947
St. Peter	1902	WENONA P	1978
STE. MARIE	1946	WEST FRANKFORT P	1978
STEELVILLE P	1983	WEST SALEM P	1967
Sterling	1887	WHEATON	1887
STOCKTON	1944	Wheeling	1888
Strawn	1900	WHITE HALL	1869
STREATOR	1893	Willow Hill	1854
Sullivan	1900	WILMETTE P	1982
Sumner	1909	Winchester	1888
Sycamore	1880	WINDSOR	1888
Tampico	1890	WOODHULL P	1978
Three Mile	1887	Woodstock	1857
Tilden	1886	Yale	1888
TISKILWA	1894	YATES CITY P	1978
Toulon	1887	Yorkville	1887
TUNNEL HILL P	1987	Zion	1894

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* earliest records from Ft. Dearborn IL

** earliest records from Davenport IA

Table 2. Early weather observers in Illinois (after Anon., 1855).

LOCATION	BEGINNING DATE	OBSERVER
Alton*	May 1849	Johnson
Athens	Jan 1843	Prof. J. Hall
Augusta*	Aug 1833	Dr. S. B. Mead
Chicago*	Jul 1832	Surgeon General S. Meacham, S. Brooks, I. I. Langguth
Elgin*	Jan 1824	Assistant Surgeon
Highland	Jan 1841	Dr. Ryhiner, and A. G. Bandelier
Jacksonville*	Apr 1849	T. Dudley & Coffin
Joliet*	Oct 1843	Dr. M. K. Brownson
Marseilles*	1858	E. P. Bosworth**
Monroe	1849	Main
Upper Alton*	1849	James
Warsaw	May 1840	Ben Whitaker
Waukegan*	1849	Joslyn

* observations continue at present, though record perhaps discontinuous
**data in diary, continuous to 1902, same observer, not yet reduced

Figure 1. Per decade, the number of weather stations beginning operation, number of stations measuring precipitation only, and the number of stations continuing operation from 1850 to the present.

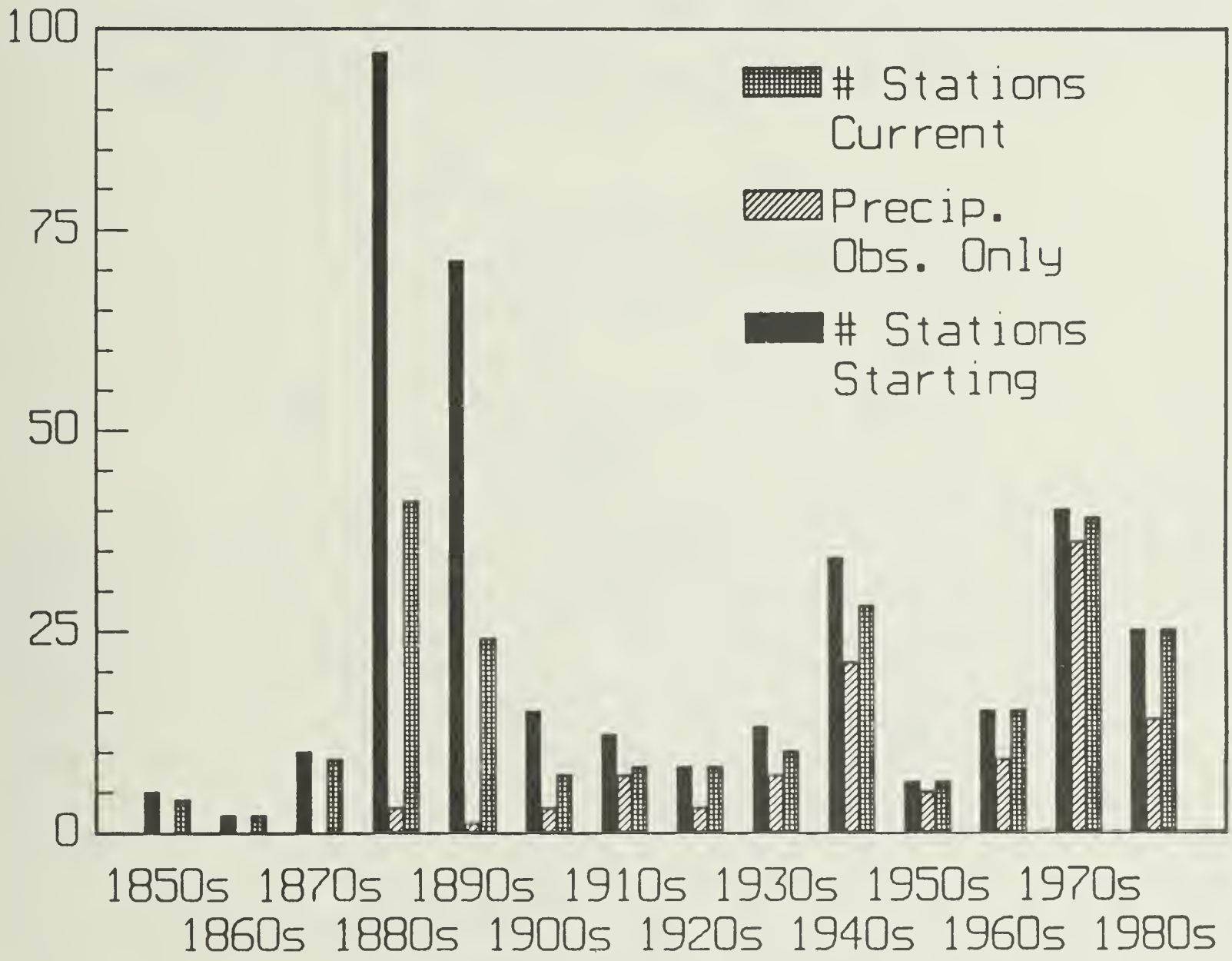
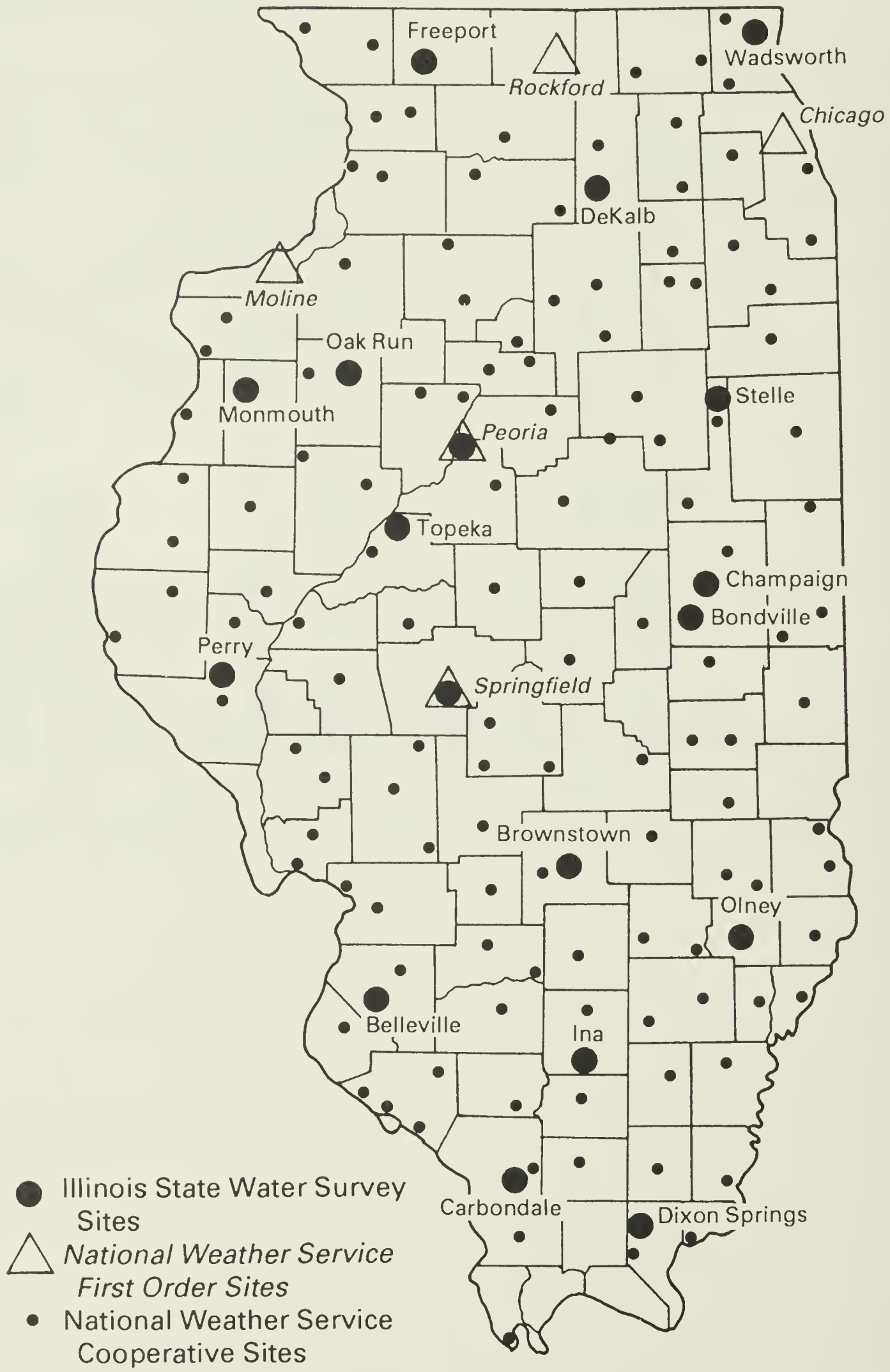


Figure 2. Distribution of weather observing sites in Illinois.



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Temporal Changes In The Climate Of Urbana-Champaign And Illinois

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INTRODUCTION

The Centennial of the Urbana (often labeled Morrow Plots) Weather Station on August 17, 1988, led to an assessment of the value of the data from this station, as well as that of other long-term weather stations in Illinois, to reveal how these unique records allow one to reconstruct and interpret the temporal fluctuations in the climate of Illinois over the past 50 to 150 years. An in-depth description of the temporal climate fluctuations during 1901-1980 across the state is available (Changnon, 1984). This paper addresses how the careful maintenance of long-term weather observations at Urbana and elsewhere by volunteer weather observers has allowed the study of climate change. Examples are presented to show how careful analysis of historical weather data at Urbana are essential to detecting important information. Information about the Urbana station, including station relocations and instrumentation since 1888, must be used since these factors affect the interpretation of the historical data and presumed climate fluctuations.

Ironically, on August 17, 1988, the date celebrating 100 years of 3,675 daily weather observations in Urbana, nature provided two record events: a record high temperature for August 17 of 101°F (breaking the record high established in 1913), and the date became the 58th day of the summer of 1988 with temperatures at or above 90°F, another new record for Urbana (and most of Illinois).

The commitment to collect weather data in Urbana and at over 240 other weather stations in Illinois is based largely on volunteer labor by "cooperative weather observers" of the National Weather Service. These observers have provided thousands of hours of effort to make weather observations, to record them, and to mail them to the National Archives. It is these data from Urbana and other comparable stations around Illinois (and the nation) that now provide us with the ability to describe and monitor the climate of Urbana, of Illinois, and of the United States. This capability has taken on new value as we enter an era where

scientists believe the future climate will change dramatically over the next 30 to 70 years throughout the world. Our ability to monitor, detect, and react to these presumed changes is no better than the quality of our climate data from this network of volunteer observers.

URBANA WEATHER STATION AND INDICATIONS OF CLIMATE FLUCTUATIONS

The first 75 years of the Urbana Weather Station had four eras relevant in the history of that station and its data quality (Changnon and Boyd, 1963). Each of these eras was marked by some form of station relocation within the campus of the University of Illinois and changes in weather shelters or instrumentation, all of which could effect certain forms of weather records.

During the first era (1888-1896), the station had begun as a part of the University's new Agricultural Experiment Station. The weather station was established to provide data for various agricultural experiments on the University farms (located close to the now existing Lincoln Hall). The second era (1897-1931) involved the relocation of the station to the famed Agronomy Plots called the "Morrow Plots." The station became a cooperative weather station with the U.S. Weather Bureau in 1902, and this act reflected a commitment of the College of Agriculture to the long-term operation of a weather station. In the ensuing years, the data from the station became a part of the local community.

Fortunately, the instrumentation bought in 1888, and maintained to present, has been of high quality and equivalent to "standard equipment." This has allowed comparison of the temperature and precipitation measurements with those at other stations of the Weather Bureau. However, the weather shelter during portions of the second era was located at an elevation higher than the "standard level" (4 feet), potentially causing the temperature values to be slightly lower than if they had been at the standard measured height.

The station's third era was from 1931-1948. It reflected decreased interest by University scientists in the Morrow Plots Station, but interest in a new weather station established on the "South Farm," 1.5 miles south of the Plots. By 1948 the College of Agriculture's interest in the station had seriously declined, and the Illinois State Water Survey (with a newly formed atmospheric sciences group) assumed station responsibility and maintained the station for the next 40 years after 60 years by the University of Illinois.

The fourth era (1949-1985) found the station maintained at the Morrow Plots location but with one minor move 100 feet south. The U.S. Weather Bureau identified it as a potential benchmark station in 1963 to help monitor climate change.

A fifth era (1985-present) began with the official relocation of the station 1.4 miles to the south campus where the Water Survey's facilities were located. Observations are maintained at the Morrow Plots Station to give data for a multi-year period for comparison of possible local differences.

The data emanating from the 100-year collection effort has allowed many research projects by University scientists interested in engineering, biology, agriculture, and water resources. Several publications have been generated by Water Survey scientists (Huff, 1949; Changnon, 1955, 1959). A few important

findings from the Urbana data are offered to illustrate applications of the data and how to interpret the findings.

Figure 1 presents the annual temperature values up through 1987. The possible effect of the taller shelter (causing slightly lower temperatures) from 1913-1931, exists. This was also a period of general climatic warming in Illinois (Changnon, 1985), and so it is difficult to isolate the effect of the shelter change in 1931 from the warming trend. As can be noted, the temperatures have declined slowly since about 1940.

The soil temperatures at 3 feet below the surface were measured during the period of 1888-1948 at Urbana. These values were used in conjunction with the air temperatures (see Fig. 1) to determine the amount of "urban effect," or heat island, developing in the Urbana temperatures (Changnon, 1964). The soil temperatures were measured at a rural site, whereas the Urbana station began in a University farm and generally rural setting in 1888, but by 1910 had become surrounded by university buildings and an enlarging community. The comparison of the deep soil temperature data and the air temperature data revealed that the mean annual air temperature between 1903 and 1947 increased 2.3°F, but that the soil temperatures increased only 1.2°F. Their difference, 1.1°F is a reflection of the growth in Champaign-Urbana and the effect of the urban "heat island." The remaining difference, 1.2°F, is due to general continental scale climatic warming during this period. Thereafter, and even though Champaign-Urbana continued to grow and the magnitude of the heat island certainly increased, the annual mean temperatures began a steady decline, as shown in Figure 1. The amount of decline presumably would have been greater had not the effect of the urban heat island continued to increase.

Figure 2 shows the annual snowfall values for Urbana from the initiation of measurements in 1903 through 1987. These reveal some interesting shifts in the winter storm climate of Urbana (and Illinois) over the past 84 years. A period of generally low snowfall values extends from about 1916 through 1950; thereafter, higher annual snowfalls occurred with peaks during the early 1960's and again during the late 1970's. The station relocations at Urbana cannot be responsible for any of the major differences found in the annual snowfall data. In all instances, exposure of the station (and where measurements were taken) was similar and susceptible to comparable conditions for snowfall measurements. Studies of Illinois winter storms (Changnon, 1969; Changnon et al., 1980) documented a very sizable increase in snowstorm frequencies across Illinois after 1960.

Table 1 presents a listing of the 20 years since 1888 having the greatest annual precipitation totals at Urbana. These values are ranked in the left column and listed chronologically in the right column. One of the important findings is that 9 of the 20 values occurred in the period from 1972-1985 (45% of the values in 14% of the years), revealing that this was a particularly wet period. In fact, only 1984 did not qualify in the 5-year period from 1981-1985, and in the 4-year period of 1972-1975, all years qualified. These 9 years were each typified by wet summers, a factor which played a major role in the locally high corn and soybean yields achieved during the 1970's and 1980's. The relatively recent increase in the number of wet years at Urbana is not related to station relocations or to a change in instruments used to measure precipitation. As will be shown in the discussions about temporal changes in the other part of Illinois in the next

section, the recent wet conditions at Urbana were found throughout Illinois (Changnon, 1984; 1985).

FLUCTUATIONS IN SELECTED CLIMATIC CONDITIONS ACROSS ILLINOIS

Several studies over the past 30 years have documented various aspects of the temporal changes in various climatic conditions across Illinois. Selected results are presented to illustrate some of the more significant fluctuations. Since most quality historical records at weather stations in Illinois began shortly before 1900, most results have focused on the climatic fluctuations during the 20th Century.

Temperature

The record of the statewide mean annual temperature from 1840 through 1985 is presented in Figure 3. The early data from 1840 through 1880 must be considered "suspect" because of relatively few weather stations and a lack of quality control of the data. Regardless, these data along with more reliable data from other parts of the East Coast suggest this was a cool period relative to what was to follow beginning in 1880.

The steady increase in Illinois temperatures from 1888 up through 1940 is shown. It's similar to that found in Urbana (Fig. 1). Thereafter, statewide temperatures systematically decreased up through 1985. Inspection of annual temperature changes for various parts of Illinois show that they occurred throughout the state (Changnon, 1985). Seasonally, the changes in temperatures since 1940 occurred in the winter (December-February) and summer (June-August) seasons (Changnon, 1984). Temporal changes in the spring and fall temperatures have been negligible; hence, the length of the Illinois growing season has not fluctuated in any systematic way during the 20th Century (Changnon, 1985).

One of the longer weather records in central Illinois is that from Peoria, with data beginning in 1856. The 10-year moving averages of January and July temperatures for Peoria up through 1980 are shown in Figure 4a and b. The January curve illustrates the relatively high temperatures of the 1930's and extreme low temperatures of the 1880's and early 1970's. The July curve shows peaks and high temperatures in the 1870's, 1930's and 1950's. Important on both graphs are the wide swings in values and the notable periods of 5 to 10 years duration with relatively high and/or low temperatures.

Precipitation

Figure 5 presents the statewide mean precipitation, based on 5-year values, for 1840-1985. This reveals the classic "see-saw" characteristic of historical precipitation records found in most continental climates like that in Illinois. Again, the early data for 1840-1880 must be considered suspect because of the paucity of stations compared to the number since that time. A wet regime across the state began in 1965 and is marked by the near-record high

values for 1981-1985. However, a drought began in 1988, and the statewide value for 1988 was 28.0 inches, the fifth lowest for the period of record.

An important measure of the temporal history of precipitation relates to growing season rainfall. Table 2 presents the frequency of wet and dry seasons per decade since 1900. Notably high frequencies of wet growing seasons are seen in the 1940's and 1970's with dry seasons frequent in 1910-19, 1930-39, and 1960-69.

The extremes of precipitation, wet and dry, have also revealed statewide fluctuations. Figure 6 is based on incidence of 12-month precipitation droughts across the state since 1905 (Changnon, 1985). To qualify as a 12-month drought, the statewide precipitation average was less than 80 percent, and at 20 percent of the weather stations in Illinois the period was rated among the five driest periods on record. This shows that the most severe droughts occurred in the 1930's and 1950's, and that since the 1950's, there have been few 12-month droughts. Further, those that have occurred were not as severe, as defined by the amount of departure of the precipitation and its areal extent across the state. Again, the tendency towards wetter conditions since 1940 are reflected in the lower incidence of droughts since that time.

Another key aspect of precipitation relates to heavy rains. The frequency of rainfall days in Illinois with 2 inches or more rain, and based on 59 stations (for 1911 through 1980) is shown in Figure 7. The curves for the warm season (April-October) and for July-August both show major fluctuations with major peaks in 2-inch rain events during 1971-80 (Huff and Changnon, 1987). The recent increase in the heavy rain events was closely related to the increases in the incidences of floods (Changnon, 1983).

The recent increases in precipitation across Illinois are illustrated by the annual values in Table 3. Here, for each crop reporting district, the annual precipitation values from 1981 to 1985 have been expressed as a percent of their normals for 1951-1980. All districts except one in one year (SE in 1981), experienced above normal values throughout this 5-year period, an unprecedented event. This extreme period of heavy precipitation was found to be related to the major increases in the levels of Lake Michigan (Changnon, 1987).

Many other aspects of the temporal nature of Illinois precipitation have been studied. For example, Changnon (1969a) analyzed growing season precipitation conditions (and temperatures) to develop models of 21 types of summer precipitation in Illinois. Then, their temporal frequency was examined. Lamb and Changnon (1982) inspected temporal distributions of seasonal precipitation in Illinois for periods ranging from 5 up to 30 years. This research attempted to determine what length of period best estimated the value in the following year. This revealed that the average of the most recent 5-year precipitation values most frequently were the best estimate of the value for the following year.

Severe Weather Conditions

Several climatological investigations have concerned the temporal variations in various severe weather conditions across Illinois. Changnon (1960)

investigated the temporal relationships between the number of warm season hail days in Illinois and the amount of crop loss due to hail. A strong relationship indicated that the frequency of hail days were a good predictor of crop loss. Problems related to historical tornado data affect their temporal distribution in Illinois (Changnon, 1982a). Temporal variations in high winds events (of a non-tornadic nature) were studied on a statewide basis. These showed periods of great incidence during the 1950's (Changnon, 1980b). The historical incidence of windblown duststorms was examined by Changnon (1982b). Peaks in windblown dust activity occurred in the droughts of the 1930's and 1950's, and then again in the spring of 1981. The incidence of severe weather conditions on calendar dates showed that certain dates, such as June 10-15, tend to have a higher likelihood of severe weather conditions than other adjacent dates (Changnon, 1962). The study of the temporal variations of severe weather events across the state also embraced severe winter storms (Changnon, 1969b; 1984). Severe winter storms peaked during the 1970's and early 1980's (Changnon, 1978; Changnon et al., 1980; and Changnon and Hilberg, 1983).

In general, the studies of various severe weather conditions, both those in the warm season (thunderstorms, hail, and tornadoes) and those in the winter season (snow and ice storms), show a large amount of temporal variability across Illinois. Many conditions had an increase in storm activity during the 1970's and 80's. This is in keeping with the cooler, cloudier, and wetter climatic conditions of recent decades.

SUMMARY

The temporal fluctuations and variations of various Illinois climatic conditions have been well documented. The continental type climate of Illinois, like that of the entire Midwest, is always in a state of fluctuation. Since the modern era of weather measurements began late in the 19th Century, Illinois has experienced two general periods. The first, from about 1890 to 1940 was one of increasing temperatures, decreasing rainfall, low incidence of storminess, and a high incidence of droughts. Since the 1940's, the Illinois climate has tended towards cooler, cloudier, and wetter conditions with increased storminess.

An oft-used description of the Illinois climate certainly applies; "Illinois has a continental climate typified by warm to hot summers with high humidity, cold and often severe winters, and with severe storms of various types in all seasons."

Knowledge of the temporal behavior of Illinois climate conditions is relevant for the design and operation of weather-sensitive systems. Growing national concern over the possibility of a future major change in global climate due to continuing atmospheric increases in CO_2 and other trace gases is of great concern to Illinois. Monitoring our climate so as to detect the onset and magnitude of this change is essential, and detecting shifts should be made easier by having documentation of the past temporal variations of the Illinois climate based on quality records.

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Table 1. The 20 largest annual precipitation totals at Urbana during 1888-1987.

Ranked Listing			Chronological Listing		
1	1927	55.64	4	1898	48.47
2	1983	50.26	9	1902	45.68
3	1973	49.37	6	1909	47.05
4	1898	48.47	18	1918	43.19
5	1945	48.01	16	1926	43.53
6	1909	47.05	1	1927	55.64
7	1981	46.00	13	1929	44.13
8	1975	45.79	5	1945	48.01
9	1902	45.68	11	1949	45.44
10	1985	45.54	19	1950	42.99
11	1949	45.44	12	1965	44.44
12	1965	44.44	17	1972	43.25
13	1929	44.13	3	1973	49.37
14	1982	43.76	15	1974	43.55
15	1974	43.55	8	1975	45.79
16	1926	43.53	20	1977	42.93
17	1972	43.25	7	1981	46.00
18	1918	43.19	14	1982	43.76
19	1950	42.99	2	1983	50.26
20	1977	42.93	10	1985	45.54

Table 2. Decadal Frequency of Wet and Dry Growing Seasons (May-August) in Illinois, 1900-1979.

	Number of Wet Seasons*	Number of Dry Seasons**
1900-1909	3	3
1910-1919	3	5
1920-1929	3	3
1930-1939	1	6
1940-1949	6	0
1950-1959	1	3
1960-1969	3	5
1970-1979	6	1

*Wet represents upper 1/3 of values.

**Dry represents lower 1/3 of values.

Table 3. Annual Precipitation Values in Illinois' Nine Crop Districts for 1 981 1985 Expressed as Percent of their 1951-1980 Average of Return Interval Values are Shown in Parenthesis.[1]

Districts	1981	1982	1983	1984	1985
NW	113 (4)	132 (10)	110 (3)	103	112 (4)
NE	105 (2)	135 (20)	131 (10)	103	115 (6)
W	116 (3)	115 (3)	107 (2)	111 (3)	124 (8)
C	127 (10)	133 (15)	109 (3)	108 (3)	119 (8)
E	121 (5)	137 (20)	115 (4)	100	125 (7)
WSW	123 (5)	134 (10)	103	121 (5)	122 (5)
ESE	107 (2)	135 (15)	116 (3)	116 (3)	126(10)
SW	103	117 (5)	110 (2)	118 (5)	124 (8)
SE	99	111 (3)	105 (2)	117 (5)	128 (12)

[1]A value of 10 means it is a value expected to occur once every 10 years.

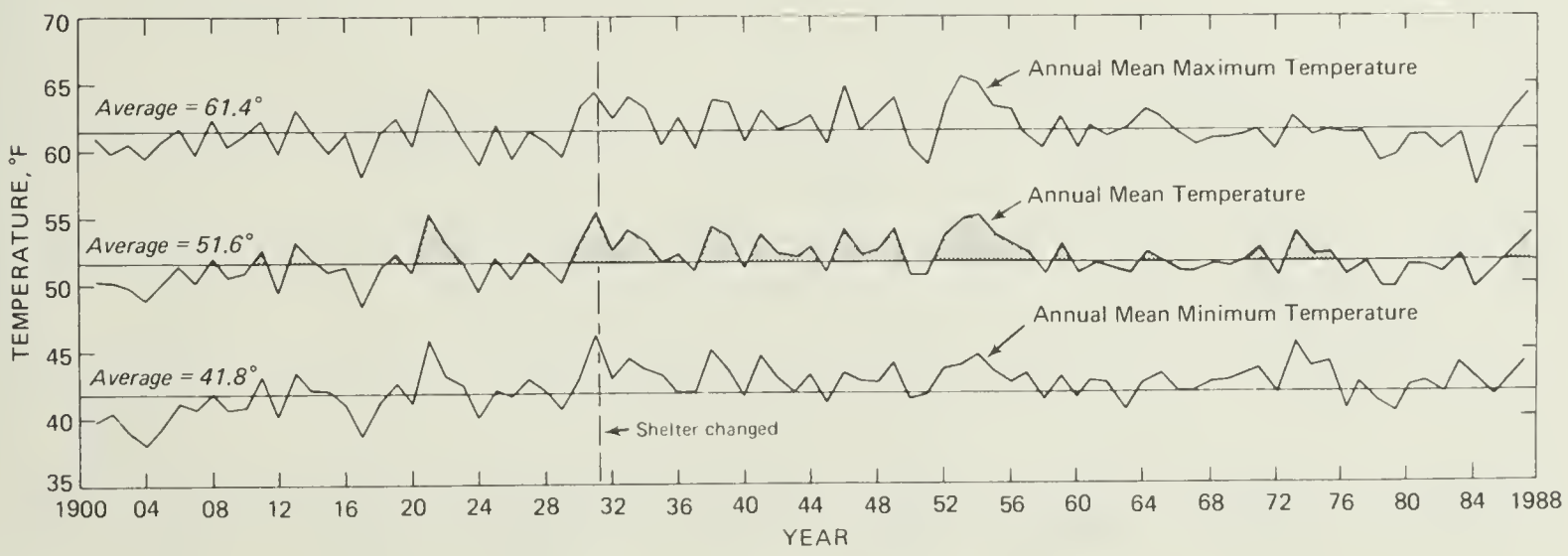

Figure 1. Annual mean temperatures (°F) at Urbana, Illinois, 1900-1987.

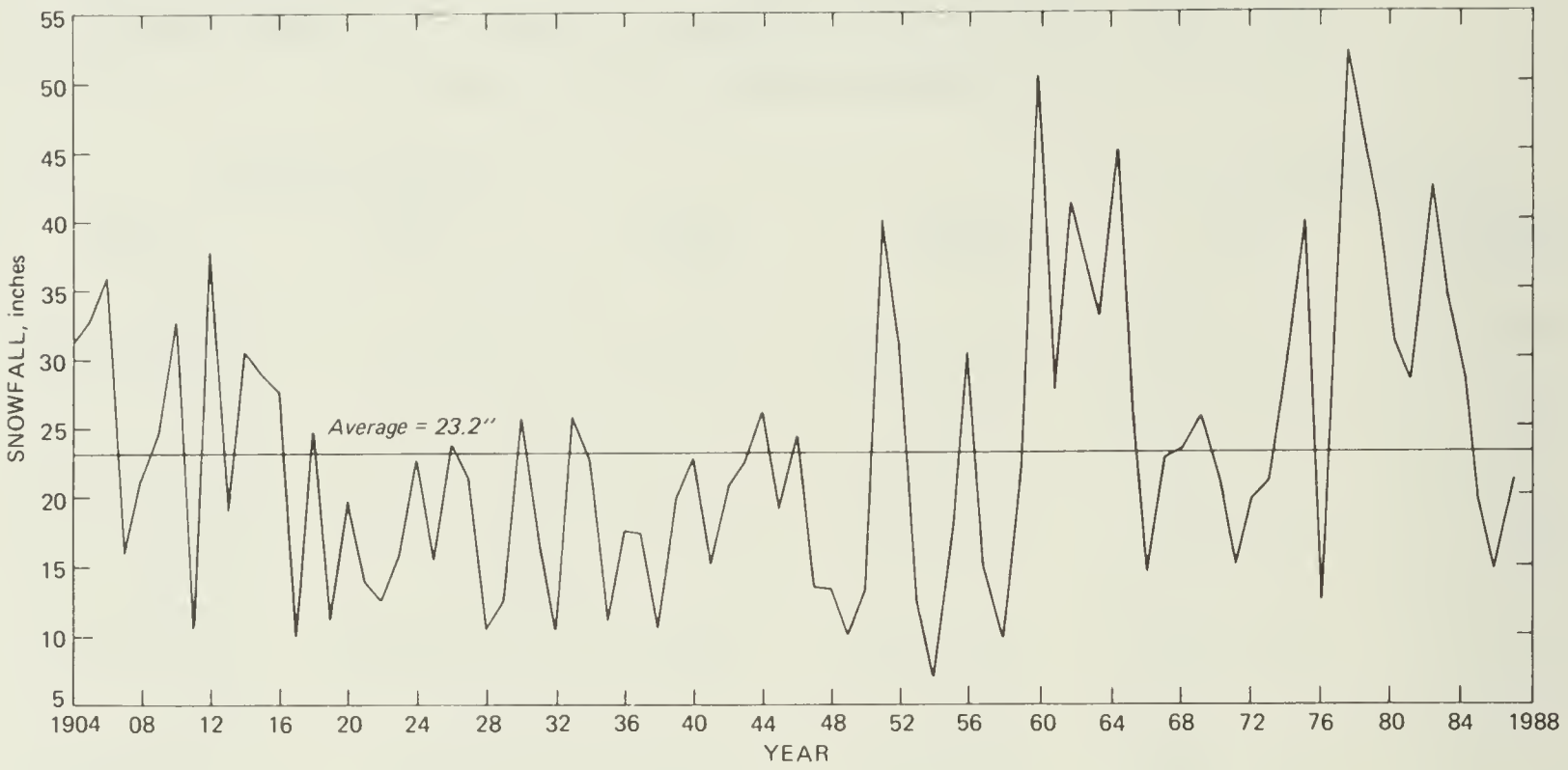

Figure 2. Annual snowfall values, in inches, at Urbana, Illinois, 1904-1987.

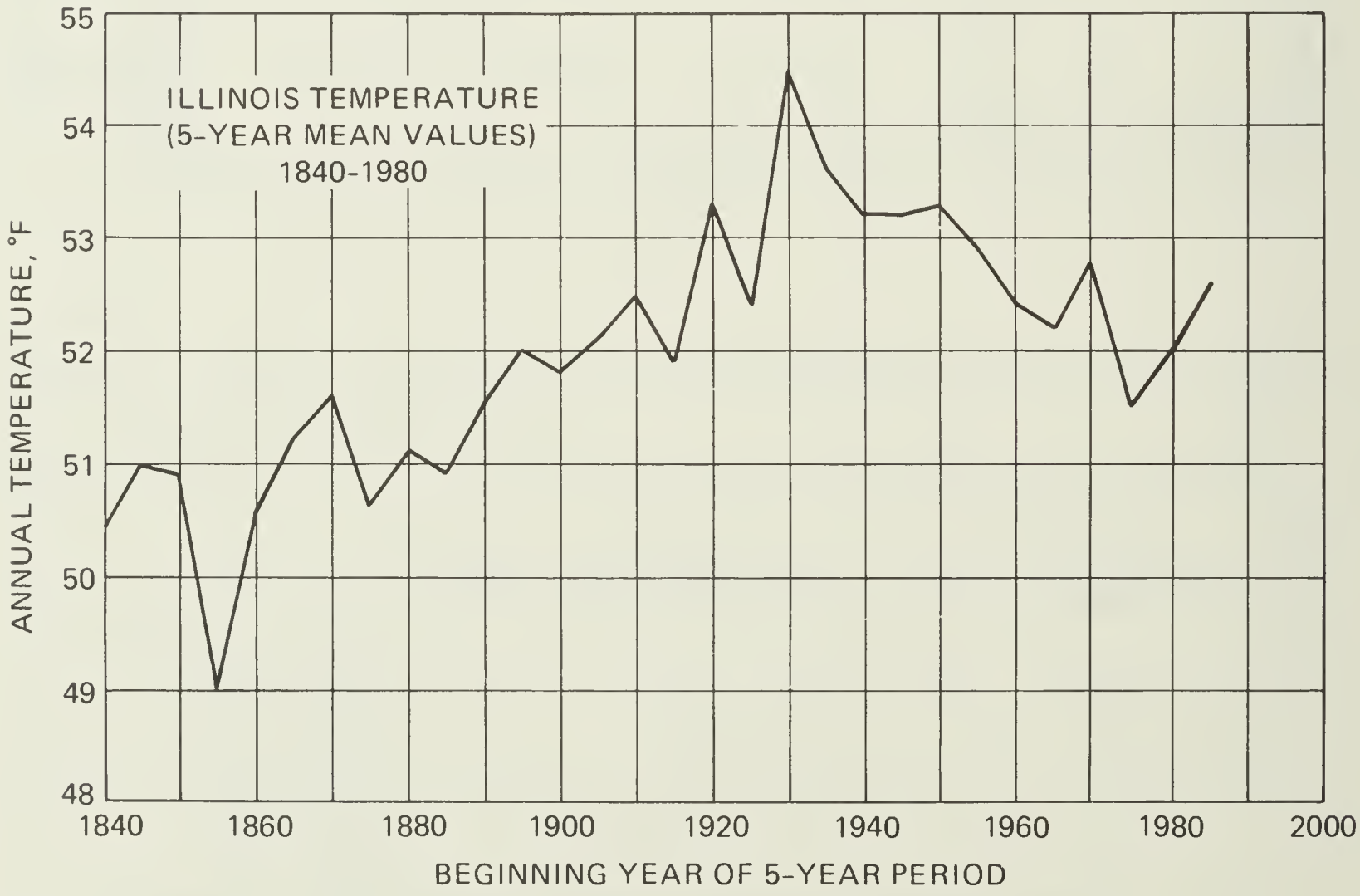

Figure 3. Illinois annual mean temperature (°F) for 5-year periods (1840-44, 1845-49, etc.) for 1840-1988.

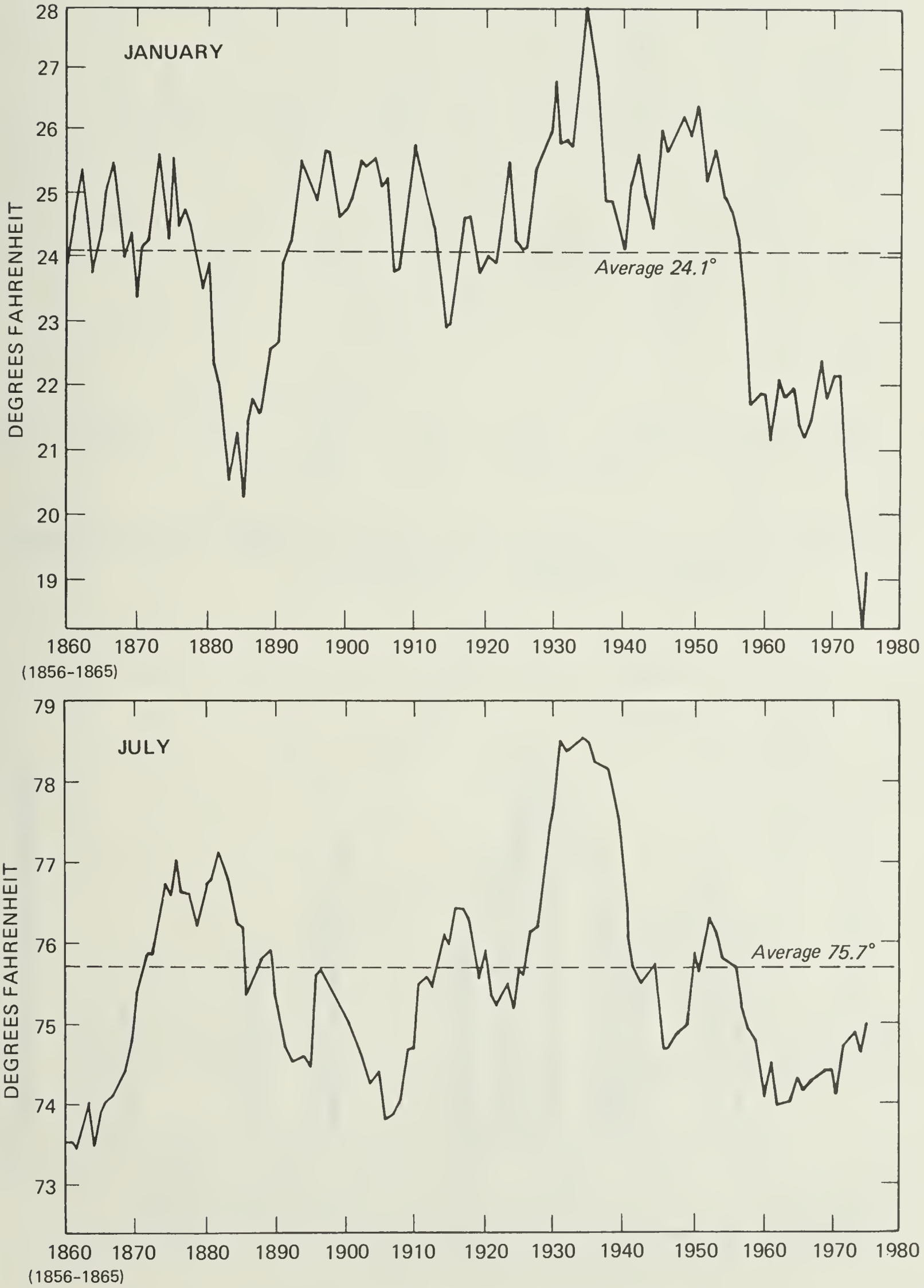

Figure 4. The 10-year moving averages of monthly mean temperatures (°F) at Peoria, 1856-1980.

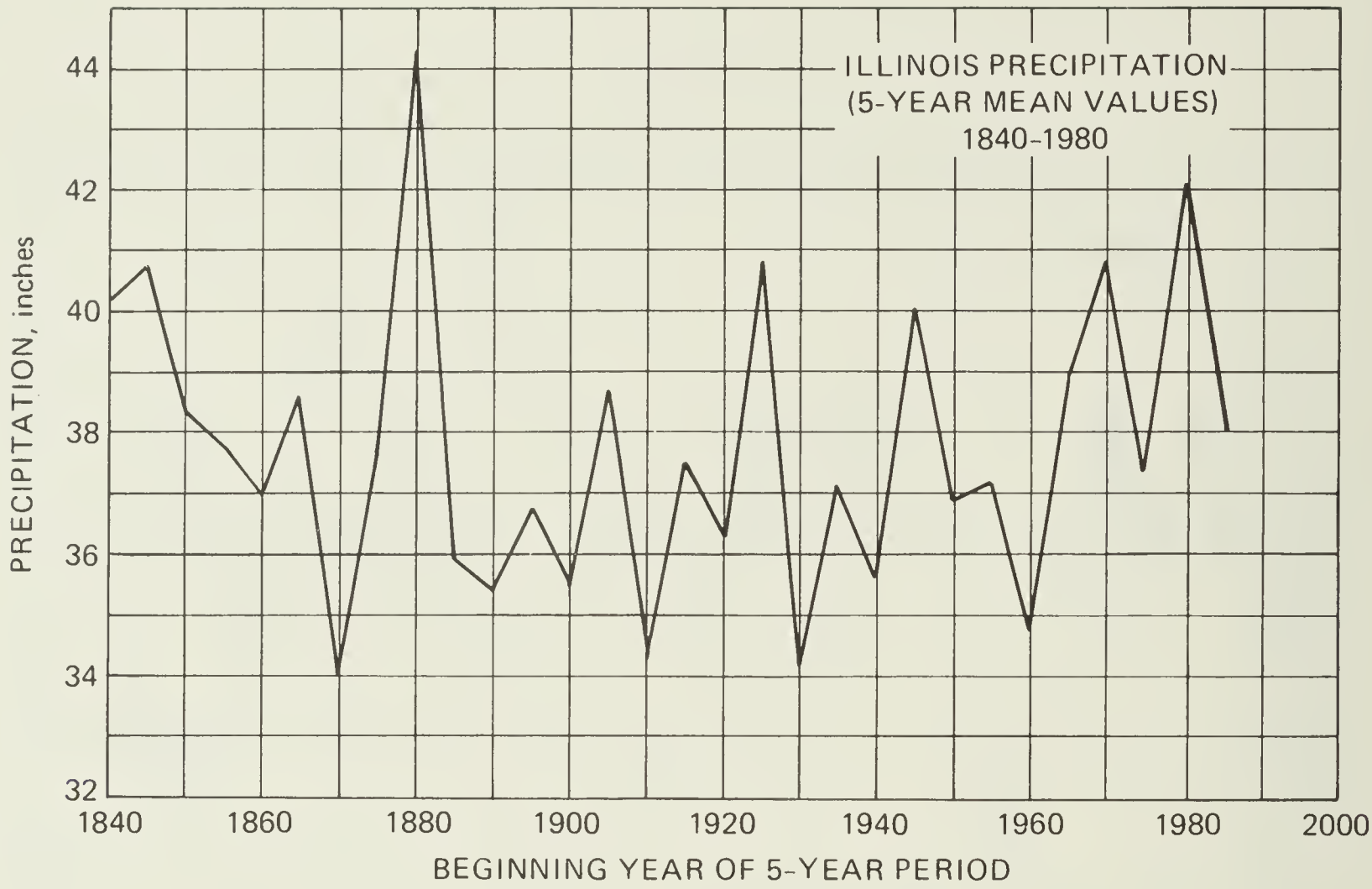

Figure 5. Illinois annual precipitation values, in inches, for 5-year periods (1840-44, 1845-49, etc.) for 1840-1988.

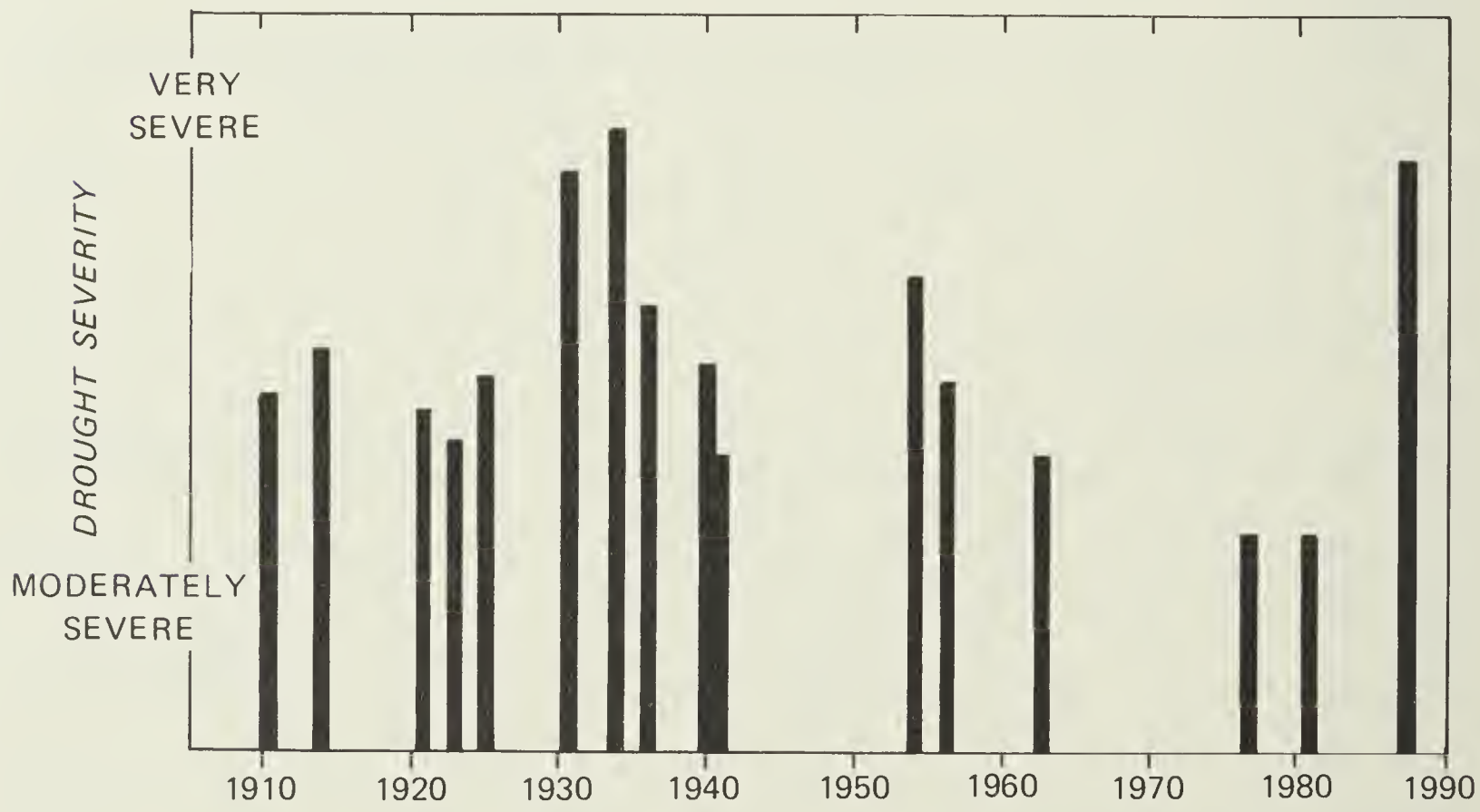

Figure 6. Severity of climatological droughts of 12-month duration in Illinois between 1905 and 1988.

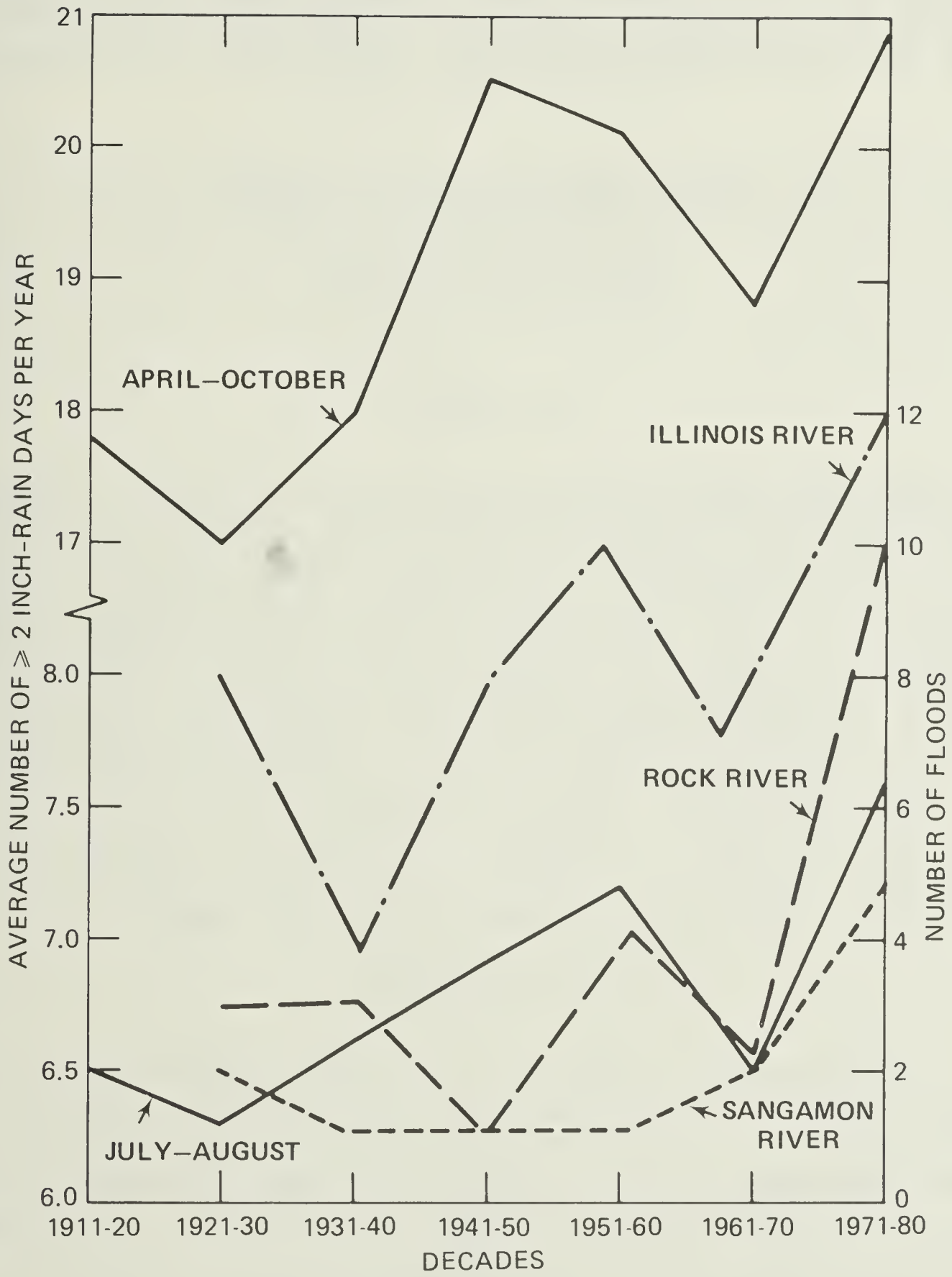

Figure 7. Decadal frequency of days with 2 or more inches of rain during April-October and July-August periods, and of floods on three rivers.

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Use of Cooperative Weather Station Data in Contemporary Climate Research

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ABSTRACT

Daily precipitation observations made at thousands of cooperative weather stations in the central U.S. and southern Canada during the May-Augusts of 1949-80 are distilled into a set for a grid-like network of 557 locations which is used to delineate areas of spatial precipitation coherence for a range of time scales and periods. This delineation is achieved by applying a variety of eigenvectorial techniques and correlation analysis to network station totals for 3, 7, 15, 30, 41, and 61 day periods. All analyses are performed for May-August as a whole; those for 3-days are also conducted on a half-monthly (early May, late May,...., late August) basis. The resulting regionalizations of the vast study domain into smaller areas of precipitation coherence are compared and their implications and applications identified. This illustrates the great value of the voluntary observers who operate the cooperative weather stations.

INTRODUCTION

The two preceding papers in this series outlined the history of cooperative weather station observations in Illinois (Wendland, 1990) and used data from some of those stations to document temporal changes in the climate of both Urbana-Champaign and the state as a whole (Changnon, 1990). Their focus was thus on the *time* dimension. This final paper in the series broadens the discussion by strongly emphasizing the *space* dimension. We show here how daily precipitation observations made at thousands of cooperative weather stations in the central U. S. and southern Canada have been used to identify important spatial patterns of summer precipitation variation for that vast area. The research employed modern advanced statistical techniques and yielded results that have diverse implications and applications for predictive crop yield modeling, mesometeorological inquiry, 48 - 96 hour precipitation prediction, studies of

climate variation and change, precipitation chemistry calculations, and perhaps watershed- and basin-scale surface hydrology. The work was made possible by the high spatial density of the cooperative station data -- no other available data source possessed this necessary characteristic -- which thus adds to the evidence in the two preceding papers of the great value of the voluntary observers who operate the cooperative stations.

DATA AND ANALYSIS

We created a new data set for use in the research on which this paper is based. It contains the individual daily precipitation totals for 557 locations in the central U. S. (402) and southern Canada (155) for the May-August periods of 1949-80, which total more than 2.19 million observations. The grid-like station network is displayed in Fig. 1; it is bounded to the west and east by the Rocky and Appalachian mountain systems, to the south by the Gulf of Mexico, and to the north by the limit of agriculture and/or the availability of precipitation stations with at least moderate density.

Full details of the construction and characteristics of this data set were presented in Richman and Lamb (1985, 1987), with only a brief overview being given here. The first step in the development of the data set was the acquisition of all daily precipitation totals archived by the U. S. National Climatic Data Center and the Canadian Climate Centre for the study region and period. This involved 11,634 stations, 98% of which were cooperative stations. After identifying the stations with the longest records, and carefully scrutinizing and quality controlling their data, it was concluded that a network resolution of 80-110 km was the finest practicable over most of the domain from the standpoints of spatial and temporal uniformity and data set completeness. A modified 1° latitude-longitude "target" grid (the meridional separation north of 49°N was held constant at the 49°N value) was therefore established, and for each intersection the nearest station with the most complete and seemingly most reliable record was identified. These stations were located, on average, 10 km (U.S.) and 24 km (Canada) from the grid intersection concerned, and were chosen to form the present data set (Fig. 1). For the days these stations did not possess observations (7% of total for U.S.; 23% for Canada), the value from one of two (U.S.) or three (Canada) adjacent "alternate" stations was substituted without adjustment. The alternate stations were usually situated within 30 km of their parent network station and were selected because their records, although often incomplete, covered the gaps in the records of the network station. The resulting data set thus contains actual daily precipitation totals for a regularly spaced array of stations, with no missing observations.

Richman and Lamb (1985, 1987, 1988, 1989) have reported the major early results of a comprehensive analysis of this data set that remains ongoing. In general, the work is applying a range of eigenvectorial techniques (unrotated and rotated Principal Components Analysis; Common Factor Analysis; Procrustes Target Analysis) and correlation analysis to various temporal amalgamations of the data (station totals for 3, 7, 15, 30, 41, and 61 day periods). Detailed information on the statistical methods employed appears in the aforementioned papers,

Richman (1986, 1987), and Richman and Easterling (1988). A key thrust of the work to date has been the use of those methods to delineate areas of spatial precipitation coherence. We present here a selection of the results that has particularly broad application.

RESULTS

Fig. 2 provides a rather complete subdivision of the study domain into regions within which three- and seven-day precipitation tends to be spatially coherent *for May-August as a whole*. It is derived from VARIMAX-rotated Principal Component analyses that are fully described in Richman and Lamb (1985, 1987). The regions identified are reasonably uniform in size and span areas equivalent to several medium-sized U. S. states. The validity of the regionalization is enhanced by the fact that, although the U. S. and Canadian analyses were performed separately, their near-border areas of spatial precipitation coherence match closely and appear very meaningful in an agricultural systems/ecosystems sense. An essentially identical regionalization was obtained when the U. S. and Canadian data were analyzed together (Richman and Lamb, 1988, Fig. 2). Some of the most notable features of the present Fig. 2 include: (a) the identification of a region that approximates much of the eastern Corn Belt (Ohio, Indiana, Kentucky, most of Illinois); (b) the linking of Wisconsin, Michigan, and southern Ontario, despite the intervening presences of Lakes Michigan and Huron, to form a "mixed agriculture" region; (c) the existence of the domain's only north-south oriented region in its arid southwest (northwest Texas and western Oklahoma-Kansas); (d) the association of North Dakota with southern Saskatchewan-Manitoba and eastern Montana (cereal production) rather than South Dakota; (e) the linking of northwestern Ontario with northern Minnesota-Wisconsin (largely forest); and (f) the isolation of the important agricultural state of Iowa from the aforementioned eastern Corn Belt region and its fragmented distribution between three of the coherent regions.

Fig. 3 contains counterparts to Fig. 2 for each half-month period during May-August. It thus provides both the basis for the overall seasonal three-seven day precipitation coherence pattern in Fig. 2 and information on the variation of areas of such precipitation coherence during May-August. Unlike Fig. 2, the analyses summarized in Fig. 3 treated the U. S. and Canadian data together. In general, the half-monthly regionalizations in Fig. 3 are quite consistent with the seasonal pattern in Fig. 2 (cf. features (a) - (f) above). The agreement is particularly strong for May-June for the study region as a whole, and for the southern half of that region for all months. Perhaps the most striking intraseasonal variation evident in Fig. 3 concerns the orientation of the areas of precipitation coherence in the zone that contains the Great Lakes. Beginning in early July and persisting through late August, the major axes of these areas tend to steadily pivot from having northwest-southeast alignments in the west to southwest-northeast alignments in the east. This hitherto unidentified feature is not apparent for May-June. It presumably reflects a key intraseasonal variation in the behavior of the precipitation-bearing systems -- probably involving the southward sagging and northward retreat of weak frontal systems -- that invites comprehensive investigation.

Richman and Lamb (1988, Table 2) have shown that the fraction of the total domain variance that is cumulatively explained by the (first) 13 VARIMAX-rotated Principal Components that are the basis for Fig. 3 decreases steadily from early May (61%) to late July (40%), and then increases through early August (44%) and late August (46%). These changes presumably reflect a May through July decrease in organized synoptic-scale precipitation and coincident increase in less organized convective precipitation, and a reversal of those trends during August. This interpretation is strongly supported by Fig. 4, which was constructed as follows. For each of the regions shown in Fig. 3 for a given half-month, the precipitation station with the highest loading on the VARIMAX-rotated Principal Component concerned was identified. Those stations were located close to the center of their region. Their three-day precipitation totals were then separately correlated with the three-day totals for the remaining 556 stations in the full network (Fig. 1) for the half-month concerned. Next, the resulting fields of correlation coefficients were isoplethed and the +0.4 correlation isopleths corresponding to each region were plotted on a single map for each half month. Fig. 4 contains all of those half-month maps. It shows that the total area enclosed by the +0.4 correlation isopleths decreases strongly from early May (when it covers almost the entire domain) until late July (approximately one-third of domain), after which it increases steadily through early and late August. As intimated above, this provides further evidence of the decreasing (increasing) importance of synoptic-scale (convective) precipitation from early May until late July, and the opposite during August.

Fig. 5 shows how the short-period (three-seven day) regionalization pattern in Fig. 2 varies as the precipitation totalling period is extended to 15, 30, 41, and 61 days. The analyses contributing to Fig. 5 treated the U. S. and Canadian data together and were *for May-August as a whole*. The regionalizations obtained for 15 and 30 days (Figs. 5a, b) are remarkably similar to their shorter-period counterpart in Fig. 2 (cf. features (a) - (f) listed above). The major difference is that the regions along the western edge of the domain have become larger (and fewer in number) by 15 and 30 days, while those in the east have shrunk in size. This trend continues as the precipitation totalling period is lengthened to 41 and 61 days (Figs. 5c, d), with the result that most of the U. S. Great Plains are spanned by two very large regions, and some of the eastern regions are further contracted. Despite this evolution, however, several of the 61-day regions have clear three-seven day counterparts in Fig. 2 (two along Gulf Coast; eastern Corn Belt; Wisconsin-Michigan-Southern Ontario; many that span U. S.-Canadian border). This variation of the areas of precipitation coherence with increasing time-scale constitutes new information that invites further investigation. It likely reflects the degree of temporal consistency of the tracks of the precipitation producing systems.

IMPLICATIONS AND APPLICATIONS

We believe that the regionalizations presented in Figs. 2-5 have a number of interesting implications and will be of considerable utility in several contexts. Some details are now provided.

The regionalizations seem particularly relevant to the predictive crop yield modeling that is now routinely performed (often at *weekly* intervals) for the growing season of the central United States by some grain merchandisers, commodity brokers, and their consultants (Lamb et al., 1985). The modelers are uncertain about the number and morphology of the regions for which individual models should be developed and utilized -- such subdivisions need to be partially climate-based -- and also about the spatial representativeness of the year-to-date meteorological data currently used to force the models at the required short intervals. These data are largely limited to observations from the sparse network of National Weather Service (NWS) first-order stations; the national delivery system for the spatially dense NWS cooperative station data used in this study is far too slow to be helpful in the above real-time situation (Lamb et al., 1985). The foregoing uncertainties are strikingly illustrated by the discrepancy between the density of the first-order network (e.g., five stations in Illinois) and the fact that some of the predictive modeling is being performed on an individual county (e.g., 102 in Illinois) scale. We believe that Fig. 2's regionalization can substantially reduce those uncertainties, particularly since it is applicable to the weekly time-scale of much of the modeling. Furthermore, should there be a need to develop and use models for separate portions of the growing season, Fig. 3's half-monthly regionalizations would likely also be helpful.

Because the regionalizations in Figs. 2 and 3 also hold for the three-day time scale, they may have utility for the 48-96 hour prediction of precipitation. Where such prediction has a common basis (e.g., statistical) for fixed areas, as is the case with the NWS Model Output Statistics (MOS) Probability of Precipitation (PoP) forecasts (Lowry and Glahn, 1976; Erickson, 1988), it would seem desirable for those areas to possess demonstrated precipitation coherence on the time scale concerned. Figs. 2 and 3 contain the latter information. Interestingly, one of the MOS PoP forecast area delineations (Lowry and Glahn, 1976, Fig. 7) grouped northern Illinois and most of Michigan with Wisconsin and northeastern Iowa, as do Fig. 2 and many of the half-monthly panels in Fig. 3. However, the NWS and present regionalizations exhibit few other similarities.

A related potential application of Figs. 2 and 3 is in studies of climatic change over the last 100-150 years. Since this work must necessarily be based on the relatively few stations with reliable long-term records (e.g., Griffiths, 1983; Changnon, 1990), there is an urgent need for information on the spatial representativeness of such stations. Figs. 2 and 3 should provide valuable guidance in that regard for investigations of the secular change in short-period precipitation behavior. For similar reasons, they may also be of some utility in the fields of rainfall chemistry (e.g., for the estimation of total areal acidic deposition from the weekly averaged point concentration values that are now available), weather modification (e.g., the siting of experiments and operations could be guided by the regional boundaries), and perhaps watershed- and basin-scale surface hydrology. Furthermore, as already indicated in the discussions of Figs. 3-5, the regionalizations have implications concerning the lifecycles and areas of activity of individual weather systems.

Finally, the spatial variation in the extent to which the three-seven day regionalization (Fig. 2) changes as the precipitation totalling period is extended to 15, 30, 41, and 61 days (Fig. 5) provides a framework for investigating how short-

period weather variations integrate to climate fluctuations. Previous climate diagnostics research has tended to neglect this important issue, and instead use monthly, seasonal, or annual data to identify patterns for only one of those time periods in a given study (reviewed in Richman and Lamb, 1985). The eigenvectorial approach employed in the research on which this paper is based particularly facilitates the inquiry into how weather integrates to climate -- it not only delineates areas of spatial precipitation coherence, but also yields formally related information on their relative precipitation abundance as functions of time.

CONCLUDING REMARKS

Our ongoing research is pursuing several of the lines of inquiry suggested by the above results and their diverse implications and applications. These opportunities are thus rooted in the valuable observations of the voluntary observers who operated thousands of cooperative weather stations during 1949-80. The continued contributions of such observers will be greatly needed as the earth and atmospheric sciences, along with Society in general, become increasingly concerned with the possibility of greenhouse gas-induced climate change and the resulting global change (National Research Council, 1986; NASA Advisory Council, 1988). Some of the scenarios for that change have suggested central North America could experience a hotter and drier summer climate by the year 2030 (Schlesinger and Mitchell, 1985; Lamb, 1987). In other words, the future summer climate of Illinois could come to resemble that of Oklahoma today. As implied by earlier discussion of (the cooperative weather station based) Fig. 5, this may well involve changes in the degree of temporal consistency of the tracks of the precipitation producing systems that affect Illinois. It is therefore likely that further research using the existing archive of historical cooperative station data will yield information that can help Society adapt to future climate change. Even more importantly, however, future cooperative station data will most certainly be needed for the difficult *research* task of detecting any such climate change.

ACKNOWLEDGEMENTS

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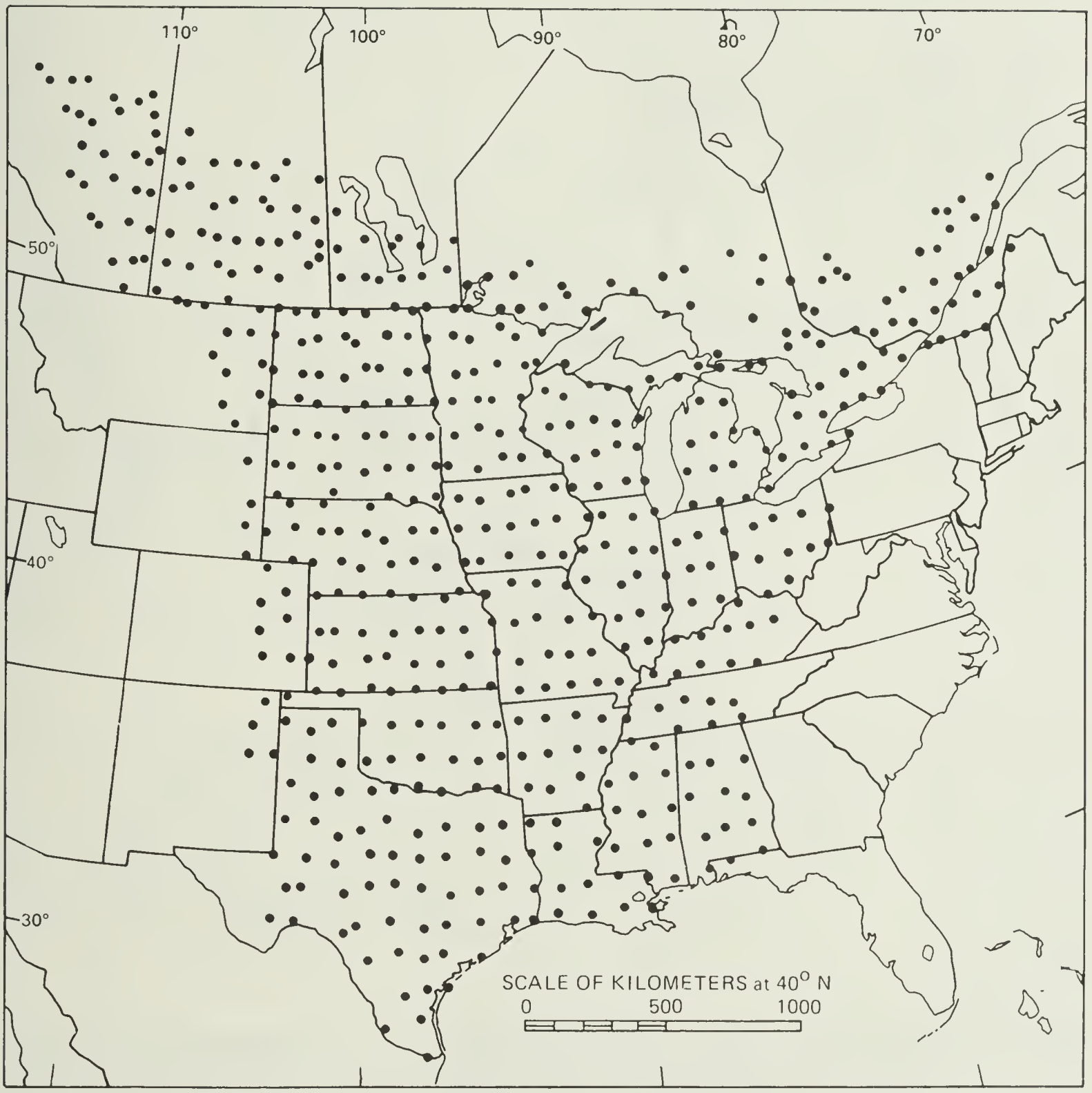

Figure 1. Station network (557) for central North American daily precipitation data set for May-August periods of 1949-80.

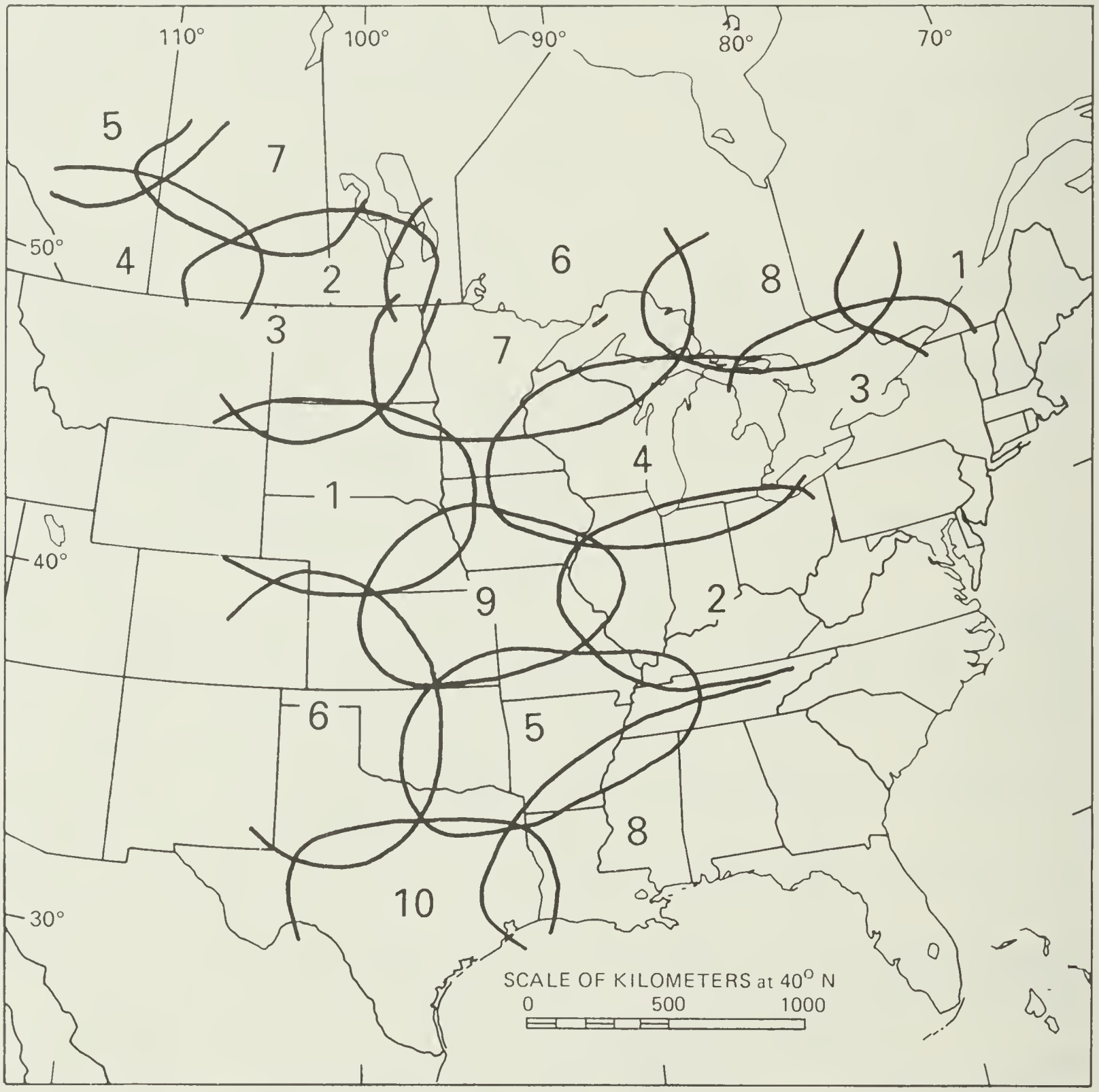

Figure 2. Combined regionalization of central U. S. with southern Canada for three-day (square-root transformed) precipitation totals during May-August. The regional boundaries are the +0.4 loading isopleths for individual VARIMAX-rotated Principal Components identified in Richman and Lamb (1985, Fig. 4; 1987, Fig. 4). The same pattern was obtained for seven-day (square-root transformed) precipitation totals (Richman and Lamb, 1985, 1987). The region numbers provide keys to associated eigenvalue and variance information in Richman and Lamb (1985, Table 2; 1987, Table 2).

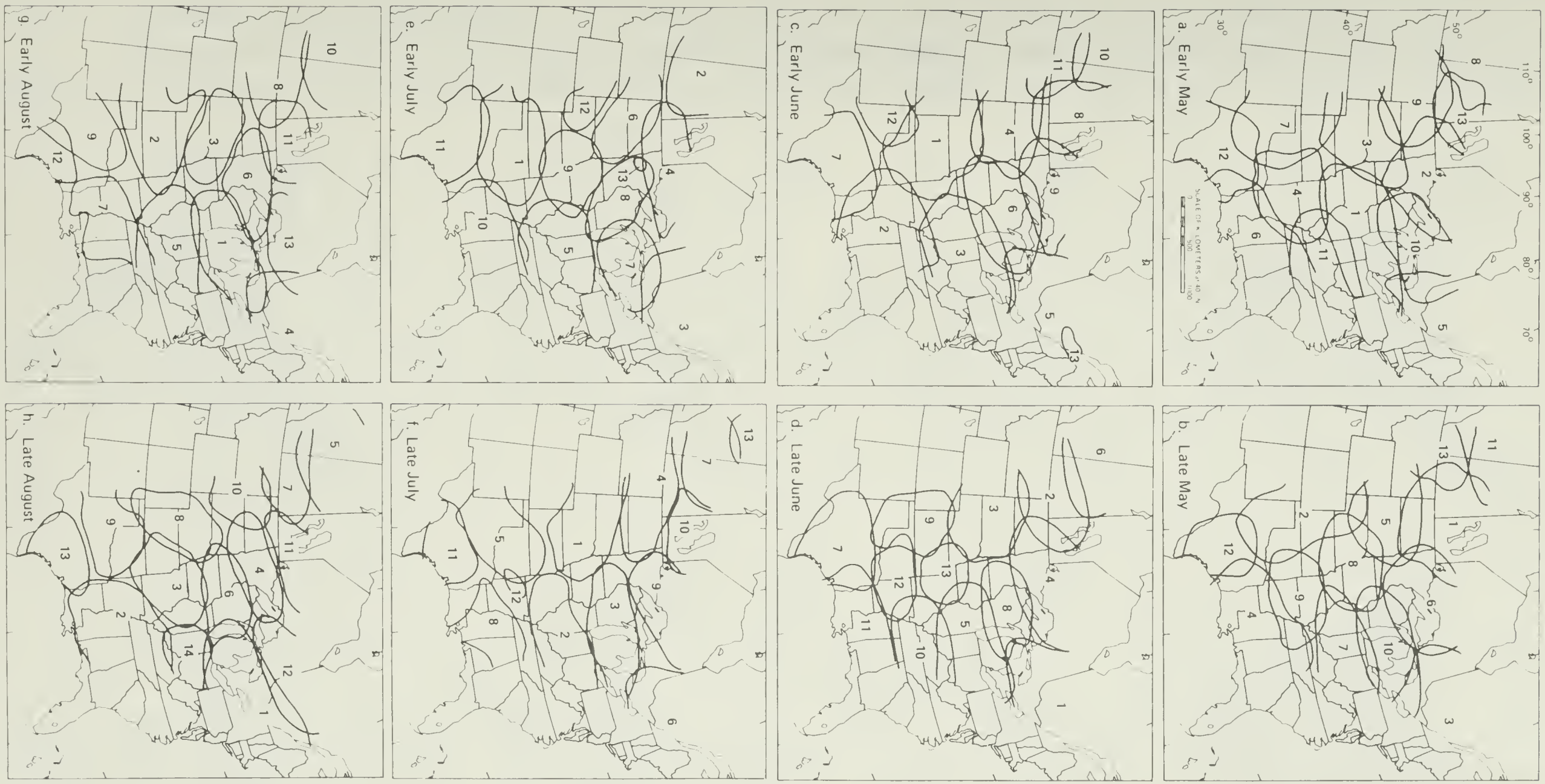

Figure 3. Regionalization of central North America for three day (square-root transformed) precipitation totals for (a) 1-15 May (early May), (b) 16-30 May (late May), (c) 31 May - 14 June (early June), (d) 15-29 June (late June), (e) 30 June - 14 July (early July), (f) 15-29 July (late July), (g) 30 July - 13 August (early August). The regional boundaries are the +0.4 loading isopleths of individual VARIMAX-rotated Principal Components, with the region numbers providing keys to associated variance information in Richman and Lamb (1988, Table 1).

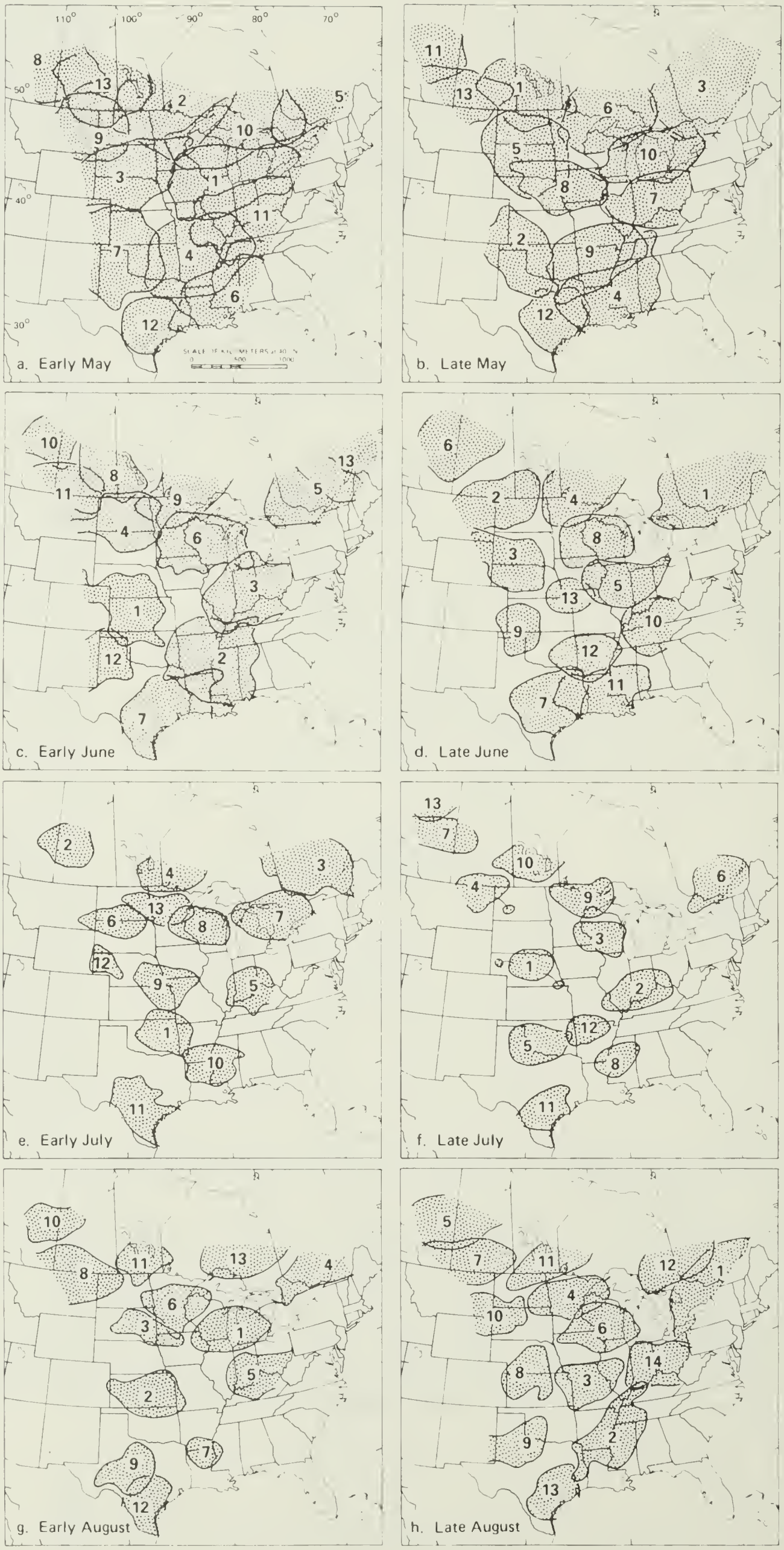

Figure 4. Correlation isopleths (+0.4) corresponding to each region delineated in each panel of Fig. 3 (see text for information on their construction). The identifying numbers are consistent with the region numbers in Fig. 3. Areas encircled by correlation isopleths are shaded.

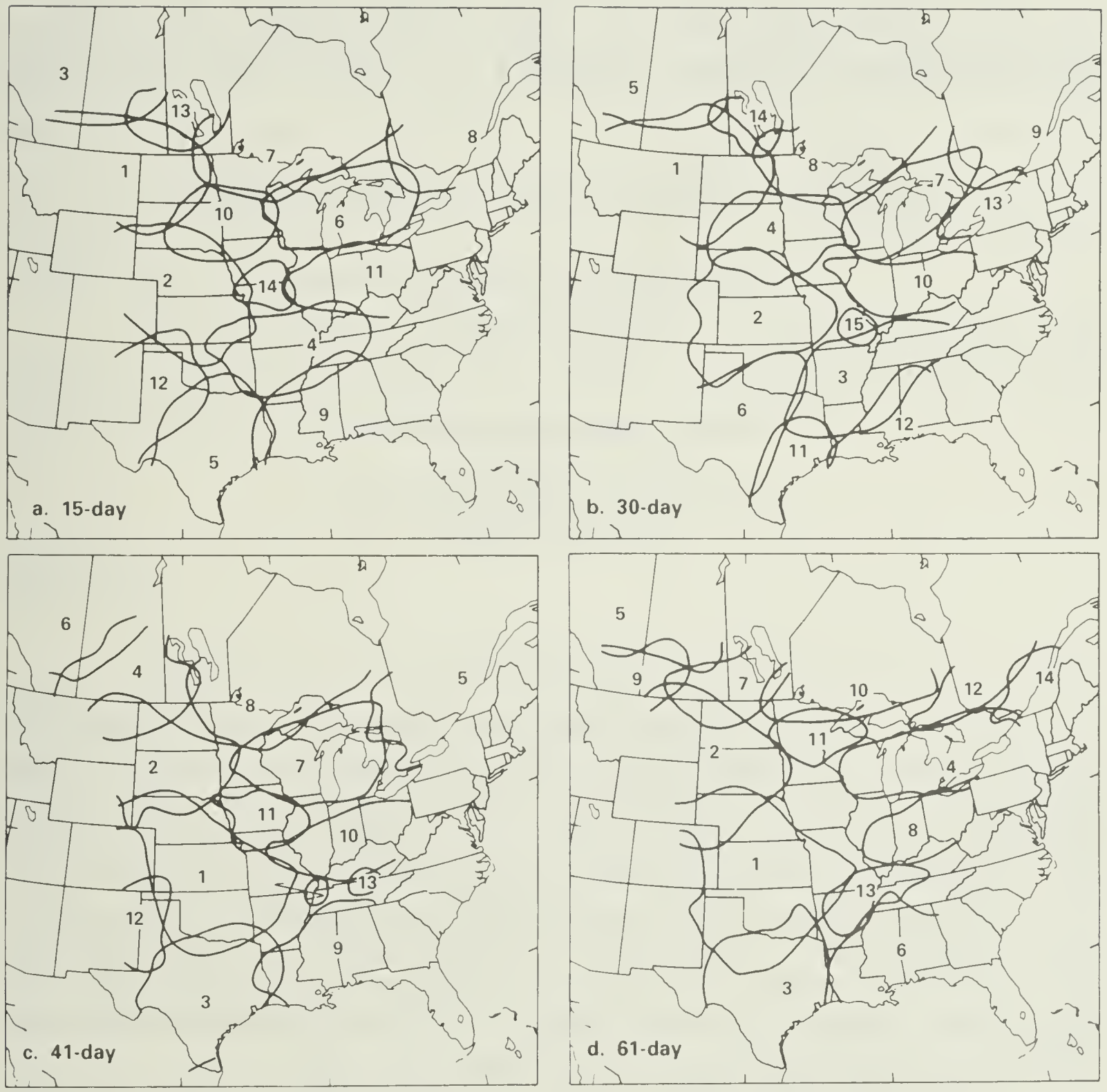

Figure 5. Regionalization of central North America for (a) 15-day (square-root transformed) precipitation totals, (b) 30-day (square-root transformed) precipitation totals, (c) 41-day precipitation totals, and (d) 61-day precipitation totals for May-August. The regional boundaries are the +0.4 loading isopleths of individual VARIMAX-rotated Principal Components, with the region numbers providing keys to associated variance information in Richman and Lamb (1988, Table 1).

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An Evaluation of the Fisheries of the Mackinaw River Basin in Central Illinois

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ABSTRACT

In 1987, on the Mackinaw River Basin in central Illinois, fish data were collected as part of an ongoing effort by the Illinois Department of Conservation (IDOC) Streams Program to assess statewide stream quality. Fifty-nine fish species were collected from 22 sites. On the Mackinaw River, stations downstream of the town of Mackinaw showed generally lower evenness, lower species richness and lower "biotic integrity" as indicated by the Alternate Index of Biotic Integrity (AIBI) , compared to stations upstream. More intensive investigations are warranted to isolate the habitat or water quality parameters responsible for this change and to determine the potential for implementation of habitat enhancement techniques in this downstream section.

Several tributaries including Panther Creek, Walnut Creek and Henline Creek were very high quality as seen with the IBI and appear to be smallmouth bass (*Micropterus dolomieui*) nurseries. Fish body condition as estimated by relative weight (Wr), was good for carp (values near 100) and fair for smallmouth bass (values ranging from 80 to 95).

With its diverse fish fauna, aesthetic value, multiple recreational uses including fishing, swimming, canoeing, and hiking, the Mackinaw River represents one of the highest quality streams in Illinois and it is within the public interest to protect this stream from deleterious impacts.

INTRODUCTION

The Mackinaw River is a major tributary of the Illinois River in central Illinois. Historically the quality of stream fisheries in this Basin has been rated "good to excellent" with 100 fish species present (Smith, 1971). At the same time dredging, siltation and agricultural pollution were also noted as factors negatively impacting the quality of the streams. Since Smith's comments nearly twenty years ago, few stream fisheries investigations have been conducted in the Mackinaw Basin. The most recent comprehensive survey of stream fisheries was conducted by Stinauer (1966, Unpubl.). Duyvejonck (1978) examined fish use of channelized and natural sections of Buck Creek and one of its unnamed tributaries. A small survey encompassing a section of the Mackinaw River and Panther Creek was conducted in 1986 (Sallee, 1986 Unpubl.).

Thus, with a limited historical perspective, the primary objective of the study was to assess the quality of the Mackinaw River Basin with respect to fish community and value as a sport fishery as part of an ongoing effort by the IDOC Stream's Program to characterize major watersheds in Illinois.

METHODS AND MATERIALS

Study Area

The Mackinaw River (Fig. 1) drains an area of approximately 1163 square miles (1516 km^2) (Healy, 1979) of the Grand Prairie Division of central Illinois (Schwegman, 1973). From its headwaters in Ford County east of Bloomington, the Mackinaw River flows 129 miles (219 km) (IDOC-Illinois Streams Information System-ISIS, 1989) in a generally westerly direction and empties into the Illinois River south of Peoria. Soils are primarily loess (Iverson, 1987) and range from brownish-gray bordering the stream to dark soils in the remainder of the watershed with non-calcareous subsoils (IL. St. Planning Comm., 1940). No major urban centers directly impact the river though several small municipalities discharge effluent into tributaries (Short, pers. comm. 1988). Channelization has occurred on 15.4% (19.9 miles) of the mainstem river (IDOC-ISIS, 1989). Land use in the watershed consists primarily of row crop agriculture with some pasture and forests along stream drainages. The Mackinaw River provides multiple recreational opportunities including fishing, swimming and canoeing.

Fish Collection

Fish were collected from 22 stations in the Mackinaw Basin from 27 July to 31 July 1987 (Fig. 1). Stations were selected based upon several criteria: amount of historical data (fish, macroinvertebrates or water quality), proximity to adjacent stations and size of stream reflecting habitat diversity and accessibility for sampling.

Boat electrofishing was conducted at 8 mainstem stations using a 12 ft. V bow boat with three booms extending from the bow. A 3-phase 3000 Watt, 230 V.A.C. generator was the power source. Both the boat operator and person at

the bow netted fish. Supplemental seine hauls were taken at 5 of these stations using a 30 ft. x 4 ft. x 0.25 in. mesh bag seine. The seine was pulled through pool or run areas while riffles were sampled by spreading the seine across the downstream end of the riffle and moving fish into the seine by kicking and turning rocks upstream of the seine.

A 30 foot electric seine, similar to one described by Larimore and Smith (1963), powered by a single phase 1400 W generator, was used at the two uppermost mainstem stations and at all tributary stations. With this method, four netters followed the seine as it was moved upstream by two persons.

Fish lengths were recorded to the nearest mm or placed in 10 mm size groups. Fish less than one kilogram were weighed to the nearest gram while larger fish were weighed to the nearest 10 grams. Small specimens were preserved in 10% formalin and identified in the laboratory according to Pflieger (1975), Smith (1979) or Becker (1983). In a few cases, often due to the small size of the specimen (usually < 30 mm) or indistinct characteristics, identification was limited to the family level.

Data Analysis

Sampling effort varied between stations thus total number and total weight for each species were converted to number/hour and grams/hour respectively. Due to difficulty in standardization, seine haul data are included only in determination of the Index of Biotic Integrity (IBI) (Karr, 1981; 1986) and in comparison of species composition with comparable historical data. Fish condition factors were calculated using relative weight (Wr) (Johnson and Nielsen, 1985) with parameters determined by Bertrand (Unpubl. IDOC data). Community similarity was evaluated using Horn's Index (Horn, 1966) which determines the amount of overlap or similarity both in number of taxa and distribution of individuals among the taxa. Values range from 0 (no similarity) to 1 (identical). Using these community similarity values, a cluster analysis was developed based upon an unweighted pair group with arithmetic averages (Sneath and Sokal, 1973). Brillouin's diversity index was recommended by Kaesler and Herricks (1976) and calculated using the BASIC program of Brower and Zar (1984).

RESULTS AND DISCUSSION

Relative Abundance and Species Composition

Fifty-nine fish species and a total of 63 taxa (includes ammocoetes, hybrids and fish identified to family) were collected in the Mackinaw Basin. Fifty-one species were collected from 10 stations on the Mackinaw River (Table 1). Catch per Unit Effort (CPUE) ranged from 237.0 fish/hour (DK-18) to 740.0 fish/hour (DK-21), while number of taxa ranged from 15 to 38 with the two furthest downstream stations DK-01 and DK-12, yielding the fewest taxa 17 and 15, respectively.

At tributary stations, CPUE ranged from 192 fish/hour to 9224.0 fish/hour (Table 2). The highest values were obtained on the Little Mackinaw River (DKE-

01) and Mud Creek (DKG-01) with 2788.0 fish/hour and 9244.0 fish/hour, respectively. Since both stations were pooled at the time of sampling, these values may reflect the concentration of fish under drought conditions as well as a related increase in sampling efficiency. Number of taxa on the tributaries ranged from 10 to 36 per station, but only 2 stations DKP-02 (Money Creek) and DKT-01 (Crooked Creek) had fewer than 22 species.

Fish Weights

On the Mackinaw River, aggregate fish weight/hour ranged from 39.8 kg/hour at (DK-20) to 83.7 kg/hour at (DK-16) and showed no longitudinal trends. Based upon weight/hour, carp (*Cyprinus carpio*) comprised the greatest proportion (26.1%) by weight of combined electrofishing samples. Other species contributing to the sample weight included river carpsucker (*Carpiodes carpio*) (18.4%), golden redhorse (*Moxostoma erythrurum*) (14.4%), gizzard shad (*Dorosoma cepedianum*) (8.0%), quillback (*Carpiodes cyprinus*) (6.5%) and smallmouth buffalo (*Ictiobus bubalus*) (5.6%).

On the tributaries, total sample weights ranged from 0.118 kg/hour at Crooked Creek (DKT-01) to 59.098 kg/hour at Panther Creek (DKK-02-A). As on the mainstem river, carp, river carpsucker, golden redhorse and quillback were generally the major constituents of aggregate weight where they occurred. However at 3 stations, Walnut Creek (DKJ-01) and PantherCreek (DKK-02, DKK-02-A) one species, gizzard shad was the major single constituent of total fish weight. At DKK-02-A this species accounted for over 40% of the fish weight. Downstream at DKK-01, gizzard shad were not collected potentially reflecting the unequal distribution of satisfactory habitat. Gizzard shad were collected in only one additional tributary, Hickory Grove Ditch (DKB-01), where conditions were apparently marginal for its existence as it comprised only about 2% of the total fish weight.

Diversity

Brillouin's diversity index assumes the entire population has been sampled (Kaesler and Herricks, 1976). For each sample, the maximum diversity may change depending upon the number of taxa and number of individuals. To normalize diversity, actual diversity is divided by the maximum diversity to obtain the evenness value (Brower and Zar, 1977). Evenness thus indicates the distribution of individuals among the taxa, relative to maximum diversity which could be obtained from a sample.

On the Mackinaw River, evenness was moderately high. With two exceptions, DK-01 (0.565) and DK-19 (0.691) in the lower reaches of the River, evenness values ranged from 0.773 to 0.858 (Table 1). Gizzard shad and emerald shiners (*Notropis atherinoides*) were the most abundant fish at stations DK-01 and DK-19, for a combined total of 75.3% of all fish in DK-01 and 49.2% in DK-19.

On the tributaries, evenness values ranged from 0.589 on Mud Creek (DKG-01) to 0.834 on Hickory Grove Ditch (DKB-01), but were typically between 0.700 and 0.800 (Table 2). At DKG-01, three species, the bluntnose minnow

(*Pimephales notatus*), common stoneroller (*Campostoma anomalum*) and sand shiner (*Notropis stramineus*) accounted for a total of 75.6% of fish distributed among 24 species in the sample.

Community Similarity

Based on community similarity, stations DK-01, DK-04, DK-12, DK-19, the most downstream stations, are more closely clustered compared to the six upstream stations (Fig. 2). Based upon percent composition, the five most abundant species in the four downstream stations were emerald shiners, gizzard shad, river carpsucker, golden redhorse and carp. In the upstream stations, golden redhorse, sand shiner, common stoneroller, red shiner (*Notropis lutrensis*) and bluntnose minnow were the five most prevalent species.

Community similarity analysis of tributary stations shows no consistent patterns (Fig. 2). This may be due to heterogeneity of fish communities both within and between these tributary basins.

Fish Condition

Relative abundance, evenness, community similarity and aggregate weight assess community composition, but do not directly reflect the condition of individual fish. Fish condition as assessed by relative weight Wr reflects food availability and general habitat suitability (Nielsen and Johnson, 1985).

Relative weight condition factors for smallmouth bass (*Micropterus dolomieui*) and common carp were calculated (Nielsen and Johnson, 1985) using a standardized equation determined by Bertrand (Unpubl. data). Only smallmouth bass ≥ 18 cm and carp ≥ 28 cm were used in the analyses. For specific size groups, relative weight values deviating substantially from 100 reflect either insufficient forage (values much less than 100) or inadequate use of available forage (values much greater than 100) (Nielsen and Johnson, 1985).

On the Mackinaw River, smallmouth bass condition (Wr) was usually between 80 and 95, but ranged as high as 112.1. On the tributaries, smallmouth bass condition ranged from a mean of 80.5 on Panther Creek (DKK-01) to 97.7 on Henline Creek (DKV-01) (Fig. 3). Carp in both the Mackinaw River and tributaries were in very good condition with Wr values approaching 100 at most stations (Fig. 4).

Index of Biotic Integrity

In comparison to preceding analyses, the Index of Biotic Integrity (IBI) examines the fish community based upon trophic composition, abundance and overall fish condition. Proposed by Karr (1981), and examined by Fausch et al. (1984) and Karr (1984; 1986) for midwestern streams, the IBI is based upon 12 factors or metrics of the fish community with total scores ranging from 12 (poor) to 60 (excellent). These values reflect the relative amount of change from optimal conditions of streams of similar size within a given IBI region. The IBI provides a consistent regional comparison of the quality of stream fisheries. As used in the Illinois Stream's Program, when condition information (i.e. % diseased, tumors,

etc.) is unavailable, an Alternate Index of Biotic Integrity (AIBI) is calculated (Bertrand, Pers. Comm. 1987). For this, the mean of the other 11 metrics is used for the condition metric.

On the Mackinaw River, AIBI values ranged from 40 (fair) to 56 (excellent). Again, lower rated stations (DK-01, DK-12) occur in the downstream reaches of the river. The highest rated samples were collected from stations DK-15, DK-17, DK-20 and DK-21 (Table 3).

AIBI values on tributaries ranged from 34 to 58. The highest quality streams included Walnut, Panther and Henline Creeks. Money and Crooked Creeks with AIBI values of 34 were the lowest rated streams sampled during the survey. Species richness for these stations was the lowest obtained in the Basin.

Historical data

An analysis of fish species composition/abundance over time can provide valuable information concerning changes in water and habitat quality. In the Mackinaw River Basin, 44 species were common between the 1966 and 1987 surveys. Eight of the 52 species collected in 1966 were not found in 1987 while 15 of the 59 species collected in 1987 were not found in 1966 (Table 4; Table 5).

Three species were collected in 1986 and not collected in 1987; however 13 species were found in 1987 and not found in 1986 (Table 5). This must be qualified by noting only seven stations (five Mackinaw River; two Panther Creek) were sampled in 1986 compared to 22 in 1987. Forty-six species common to both the 1986 and 1987 surveys were collected at these seven stations (Table 4; Table 5). Collection in 1987 of the black redhorse (*Moxostoma duquesnei*), pugnose minnow (*Notropis emiliae*), spotfin shiner (*N. spilopterus*), blacknose dace (*Rhinichthys atratulus*), and walleye (*Stizostedion vitreum*) suggests improved conditions as these are "intolerant" species not found in 1966.

Of special interest is the increase in the black redhorse. Two previous collections have been recorded from this Basin (L. Page, Pers. Comm. 1988). Compared to other sucker species, the black redhorse is less tolerant of siltation (Smith, 1979). Though impact from point-source pollution has historically been minimal on the Mackinaw River (Short, 1988 Pers. Comm.) the presence of the black redhorse and the other sensitive species suggests even further improvement in water quality within the past 20 years. With reference to AIBI values, there were no substantial differences on the Mackinaw River between 1986 and 1987 (Table 3). Differences in Panther Creek values may be attributable to sampling methods where minnow seine hauls were taken in 1986 while the newly acquired electric seine was used the following year.

CONCLUSIONS

On the Mackinaw River, distinct differences were apparent in the fish community with respect to river reach. Species richness, AIBI, and evenness values indicate lower quality stations in the reach downstream of the town of Mackinaw. Community similarity analysis showed samples from the four downstream stations were more similar to each other than to samples from the six

upstream stations. Often habitat parameters are interrelated as shown by Sheldon (1968) in examining species diversity and longitudinal succession in stream fishes. Thus, a more intensive sampling effort is needed to isolate specific factors impacting this downstream section to determine methods for habitat restoration.

The 1987 survey findings support the assessment of Smith (1971), rating the Mackinaw Basin fish community as "good to excellent". In comparison to historical collections, increases in occurrence of species intolerant of poor water quality or habitat impacted by suspended sediments or siltation also corroborate with this evaluation. The mainstem above the town of Mackinaw along with several tributaries (Panther, Henline and Walnut Creeks) are among the most valuable fisheries in the region. These streams provide valuable sportfish nurseries as typified by Henline Creek where 84.8% of the smallmouth bass collected were less than 100 mm.

Body condition for carp was good with Wr values (near 100) indicating optimal use of food resources, while condition of smallmouth bass was fair, indicating some stress due to insufficient forage or habitat limitations.

The collection of 49 species from five Mackinaw River stations and two Panther Creek stations in 1986 elucidates the ecological value of this section of the Basin. Impoundment of this reach of the river, as has been proposed in recent years would result in a substantial loss to our state's aquatic resources. Due to their diverse fish fauna, aesthetic and recreational values, the Mackinaw River and its tributaries should receive protection from any development or land-use practices which might have deleterious impacts.

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Table 1. Relative abundance (Number/Hour) diversity and evenness values for fish from Mackinaw River stations. Stations are arranged in longitudinal order from downstream (DK-01) to upstream (DK-21). Seine haul data "SH" indicates total number of fish collected for number of hauls ( ).

Minutes of electrofishing	60	30		67		50		60		47		60	40	45	30
Method(a)	EF/AC	SH(1)	EF/AC	SH(2)	EF/AC	SH(2)	EF/AC	SH(2)	EF/AC	SH(9)	EF/AC	EF/AC	EF/AC	ES/AC	ES/AC
Station	DK-01	DK-12	DK-12	DK-19	DK-19	DK-04	DK-04	DK-15	DK-15	DK-16	DK-16	DK-17	DK-18	DK-20	DK-21
1 American eel Anguilla rostrata	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2 Longnose gar Lepisosteus osseus	0.0	0.0	2.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	1.3	0.0	1.5	0.0	0.0
3 Shortnose gar Lepisosteus platostomus	2.0	0.0	4.0	0.0	9.0	0.0	2.4	0.0	2.0	1.0	0.0	0.0	0.0	0.0	0.0
4 Gizzard shad Dorosoma cepedianum	147.0	30.0	12.0	13.0	68.4	0.0	81.6	0.0	18.0	0.0	35.1	15.0	22.5	2.6	0.0
5 Carp Cyprinus carpio	16.0	0.0	16.0	0.0	15.3	0.0	20.4	0.0	15.0	0.0	42.9	16.0	9.0	11.7	4.0
6 Creek chub Semotilus atromaculatus	0.0	0.0	0.0	2.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	2.6	0.0
7 Hornyhead chub Nocomis biguttatus	1.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	1.0	2.0	0.0	14.0	0.0	11.7	80.0
8 Silver chub Hybopsis storeriana	0.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9 Suckermouth minnow Phenacobius mirabilis	0.0	0.0	2.0	6.0	2.7	0.0	0.0	2.0	47.0	3.0	0.0	35.0	0.0	1.3	4.0
10 Emerald shiner Notropis atherinoides	216.0	79.0	94.0	54.0	177.3	31.0	46.8	18.0	32.0	226.0	2.6	1.0	0.0	0.0	0.0
11 Striped shiner Notropis chrysocephalus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	3.0	1.5	19.5	40.0
12 Bigmouth shiner Notropis dorsalis	0.0	0.0	0.0	229.0	0.9	9.0	3.6	0.0	1.0	17.0	0.0	0.0	0.0	11.7	8.0
13 Red shiner Notropis lutrensis	8.0	27.0	12.0	79.0	19.8	58.0	18.0	104.0	27.0	211.0	11.7	44.0	4.5	45.5	24.0
14 Rosyface shiner Notropis rubellus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	5.2	18.0
15 Spotfin shiner Notropis spilopterus	0.0	0.0	0.0	0.0	0.9	0.0	0.0	7.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
16 Sand shiner Notropis stramineus	0.0	5.0	20.0	12.0	1.8	19.0	3.6	17.0	76.0	46.0	23.4	30.0	12.0	89.7	28.0
17 Redfin shiner Notropis umbratilis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	3.9	4.0
18 Steelcolor shiner Notropis whipplei	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.2	0.0
19 Bluntnose minnow Pimephales notatus	0.0	0.0	0.0	30.0	7.2	48.0	15.6	4.0	34.0	1.0	5.2	12.0	13.5	14.3	54.0
20 Common stoneroller Campostoma anomalum	0.0	0.0	0.0	3.0	0.0	0.0	1.2	7.0	8.0	8.0	1.3	91.0	0.0	16.9	138.0
21 Smallmouth buffalo Ictiobus bubalus	6.0	0.0	14.0	0.0	9.9	0.0	6.0	0.0	7.0	0.0	9.1	4.0	10.5	0.0	0.0
22 Bigmouth buffalo Ictiobus cyprinellus	0.0	0.0	0.0	0.0	1.8	0.0	1.2	0.0	0.0	0.0	0.0	4.0	0.0	0.0	0.0
23 Black buffalo Ictiobus niger	0.0	0.0	0.0	0.0	1.8	0.0	2.4	0.0	5.0	0.0	3.9	4.0	3.0	0.0	0.0
24 River carpsucker Carpiodes carpio	28.0	1.0	42.0	13.0	45.0	0.0	50.4	0.0	34.0	0.0	18.2	9.0	15.0	16.9	8.0
25 Quillback Carpiodes cyprinus	9.0	2.0	0.0	10.0	19.8	0.0	0.0	0.0	3.0	1.0	6.5	4.0	16.5	9.1	44.0
26 Highfin carpsucker Carpiodes velifer	0.0	0.0	0.0	0.0	5.4	0.0	2.4	0.0	1.0	0.0	2.6	0.0	0.0	1.3	0.0
27 Silver redhorse Moxostoma anisurum	0.0	0.0	0.0	1.0	5.4	1.0	4.8	0.0	2.0	0.0	1.3	5.0	3.0	1.3	0.0
28 Black redhorse Moxostoma duquesnei	0.0	1.0	0.0	0.0	10.8	0.0	7.2	0.0	6.0	0.0	10.4	6.0	25.5	2.6	0.0
29 Golden redhorse Moxostoma erythrurum	15.0	0.0	14.0	4.0	27.0	1.0	34.8	0.0	31.0	1.0	37.7	25.0	31.5	46.8	122.0
30 Shorthead redhorse Moxostoma macrolepidotum	8.0	0.0	6.0	0.0	12.6	0.0	18.0	0.0	9.0	1.0	3.9	9.0	9.0	6.5	4.0

31 Northern hogsucker Hypentelium nigricans	1.0	1.0	0.0	0.0	3.6	0.0	1.2	5.0	41.0	9.0	7.8	25.0	9.0	1.3	34.0
32 White sucker Catostomus commersoni	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.0
33 Channel catfish Ictalurus punctatus	2.0	0.0	20.0	0.0	4.5	1.0	2.4	0.0	8.0	0.0	1.3	1.0	0.0	0.0	0.0
34 Flathead catfish Pylodictis olivaris	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	1.3	0.0
35 Stonecat Notorus flavus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	4.0	7.0	0.0	29.0	0.0	6.5	4.0
36 White bass Morone chrysops	4.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
37 Smallmouth bass Micropterus dolomieui	0.0	0.0	0.0	2.0	6.3	2.0	8.4	0.0	17.0	3.0	6.5	6.0	3.0	3.9	32.0
38 Largemouth bass Micropterus salmoides	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.6	1.0	0.0	0.0	0.0
39 Green sunfish Lepomis cyanellus	0.0	0.0	0.0	0.0	1.8	0.0	12.0	0.0	0.0	0.0	7.8	4.0	0.0	3.9	6.0
40 Bluegill Lepomis macrochirus	3.0	0.0	0.0	0.0	0.9	0.0	14.4	0.0	1.0	0.0	2.6	6.0	0.0	0.0	0.0
41 Longear sunfish Lepomis megalotis	0.0	0.0	0.0	0.0	0.0	2.0	9.6	0.0	2.0	0.0	3.9	19.0	30.0	18.2	48.0
42 Rock bass Ambloplites rupestris	0.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0	6.0	0.0	6.5	12.0	7.5	20.8	10.0
43 White crappie Poxomis annularis	0.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0	1.0	0.0	2.6	1.0	1.5	0.0	0.0
44 Walleye Stizostedion vitreum	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
45 Blackside darter Percina maculata	0.0	0.0	0.0	0.0	0.0	2.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	6.5	0.0
46 Slenderhead darter Percina phoxocephala	0.0	0.0	0.0	1.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
47 Fantail darter Etheostoma flabellare	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	1.0	0.0	2.0	0.0	0.0	0.0
48 Johnny darter Etheostoma nigrum	0.0	0.0	0.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0
49 Orangethroat darter Etheostoma spectabile	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	1.5	0.0	4.0
50 Banded darter Etheostoma zonale	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	0.0	5.2	0.0
51 Freshwater drum Aplodinotus grunniens	15.0	0.0	16.0	0.0	24.3	0.0	7.2	0.0	7.0	0.0	3.9	1.0	6.0	1.3	0.0
Ammocoetes	0.0	0.0	0.0	0.0	3.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Green X Longear sunfish hybrid	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.0	0.0	0.0	0.0
Unidentified Carpiodes	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unidentified Centrarchidae	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unidentified Cyprinidae	0.0	0.0	2.0	2.0	7.2	28.0	4.8	0.0	0.0	5.0	0.0	0.0	0.0	0.0	0.0
Total number of Fish/Hour (b)	482.0	146.0	276.0	467.0	498.6	205.0	382.8	174.0	448.0	543.0	263.9	449.0	237.0	395.2	740.0
Total number of Species	17	8	14	16	30	12	27	13	31	16	27	38	22	31	24
Total number of Taxa (c)	17	8	15	17	32	15	28	13	31	17	28	38	22	31	24
Number of Species (All methods)			17		34		28		35		33				
Number of Taxa (All methods)			18		36		31		35		35				
Brillouin's Diversity (Base e)(b)	1.576		2.090		2.362		2.604		2.698		2.695	2.805	2.637	2.722	2.556
Brillouin's Evenness (Base e)	0.565		0.780		0.691		0.791		0.801		0.840	0.773	0.858	0.802	0.802

(a) EF/AC = Boat electrofishing (A.C. current), ES/AC = Electric Seine (A.C. current), SH = Seine Hauls
(b) Calculated for electrofishing data only. (c) Includes hybrids, ammocoetes and unidentified categories

Table 2. Relative abundance (Number/Hour), diversity and evenness values for fish from tributary stations.

Minutes of electrofishing	30	40	15	32.5	35	30	33	30	30	30	30	30
Method(a)	ES/AC	ES/AC	ES/AC	ES/AC	ES/AC	ES/AC	ES/AC	ES/AC	ES/AC	ES/AC	ES/AC	ES/AC
Station	DKB-01	DKE-01	DKG-01	DKJ-01	DKK-01	DKK-02	DKK-02-A	DKKB-01	DKKC-01	DKP-02	DKT-01	DKV-01
1 Shortnose gar Lepisosteus platostomus	12.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2 Gizzard shad Dorosoma cepedianum	18.0	0.0	0.0	61.2	0.0	54.0	76.5	0.0	0.0	0.0	0.0	0.0
3 Carp Cyprinus carpio	0.0	1.5	4.0	9.0	0.0	8.0	10.2	0.0	0.0	0.0	0.0	0.0
4 Creek chub Semotilus atromaculatus	0.0	237.0	204.0	1.8	40.8	10.0	18.7	24.0	256.0	410.0	36.0	34.0
5 Hornyhead chub Nocomis biguttatus	0.0	12.0	40.0	70.2	124.1	2.0	1.7	122.0	62.0	154.0	2.0	40.0
6 Blacknose dace Rhinichthys atratulus	0.0	15.0	0.0	0.0	6.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7 Suckermouth minnow Phenacobius mirabilis	0.0	333.0	384.0	12.6	122.4	4.0	0.0	6.0	26.0	0.0	0.0	0.0
8 Emerald shiner Notropis atherinoides	8.0	0.0	0.0	9.0	20.4	4.0	0.0	0.0	0.0	0.0	0.0	4.0
9 Striped shiner Notropis chrysocephalus	2.0	115.5	136.0	163.8	42.5	90.0	1.7	194.0	384.0	58.0	12.0	132.0
10 Bigmouth shiner Notropis dorsalis	2.0	619.5	100.0	0.0	180.2	0.0	3.4	2.0	236.0	326.0	50.0	10.0
11 Pugnose minnow Notropis emiliae	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0
12 Red shiner Notropis lutrensis	6.0	30.0	468.0	27.0	176.8	26.0	32.3	10.0	82.0	82.0	0.0	0.0
13 Rosyface shiner Notropis rubellus	0.0	0.0	20.0	0.0	20.4	0.0	0.0	0.0	4.0	0.0	0.0	0.0
14 Spotfin shiner Notropis spilopterus	0.0	22.5	0.0	14.4	3.4	64.0	0.0	0.0	0.0	36.0	0.0	0.0
15 Sand shiner Notropis stramineus	2.0	69.0	1780.0	10.8	341.7	0.0	3.4	4.0	322.0	146.0	0.0	4.0
16 Redfin shiner Notropis umbratilis	0.0	0.0	16.0	5.4	6.8	0.0	3.4	10.0	10.0	30.0	0.0	4.0
17 Steelcolor shiner Notropis whipplei	0.0	0.0	8.0	3.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18 Silvery minnow Hybognathus nuchalis	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0
19 Bluntnose minnow Pimephales notatus	4.0	31.5	3196.0	280.8	103.7	182.0	28.9	358.0	286.0	672.0	4.0	38.0
20 Common stoneroller Campostoma anomalum	0.0	747.0	1996.0	127.8	311.1	60.0	1.7	88.0	342.0	30.0	52.0	78.0
21 Smallmouth buffalo Ictiobus bubalus	0.0	0.0	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22 Bigmouth buffalo Ictiobus cyprinellus	0.0	0.0	0.0	0.0	0.0	0.0	1.7	0.0	0.0	0.0	0.0	0.0
23 River carpsucker Carpiodes carpio	10.0	0.0	0.0	0.0	8.5	4.0	6.8	0.0	0.0	0.0	0.0	0.0
24 Quillback Carpiodes cyprinus	8.0	0.0	28.0	16.2	42.5	12.0	18.7	0.0	0.0	0.0	0.0	0.0
25 Highfin carpsucker Carpiodes velifer	4.0	0.0	0.0	3.6	1.7	8.0	10.2	0.0	0.0	0.0	0.0	0.0
26 Silver redhorse Moxostoma anisurum	2.0	0.0	0.0	7.2	1.7	14.0	15.3	0.0	0.0	0.0	0.0	0.0
27 Black redhorse Moxostoma duquesnei	14.0	16.5	0.0	7.2	5.1	0.0	1.7	0.0	0.0	0.0	0.0	0.0
28 Golden redhorse Moxostoma erythrurum	34.0	48.0	368.0	70.2	54.4	46.0	42.5	56.0	2.0	0.0	0.0	12.0
29 Shorthead redhorse Moxostoma macrolepidotum	18.0	0.0	0.0	19.8	17.0	8.0	3.4	4.0	0.0	0.0	0.0	4.0
30 Northern hogsucker Hypentelium nigricans	8.0	18.0	68.0	86.4	37.4	10.0	0.0	34.0	0.0	0.0	0.0	30.0
31 White sucker Catostomus commersoni	0.0	111.0	272.0	0.0	3.4	4.0	0.0	32.0	18.0	4.0	0.0	84.0

32 Black bullhead Ictalurus melas	0.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
33 Yellow bullhead Ictalurus natalis	2.0	7.5	0.0	3.6	0.0	0.0	0.0	2.0	16.0	32.0	0.0	0.0
34 Channel catfish Ictalurus punctatus	6.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
35 Stonecat Notorus flavus	0.0	0.0	36.0	1.8	8.5	0.0	0.0	2.0	2.0	2.0	0.0	4.0
36 Blackstripe topminnow Fundulus notatus	0.0	0.0	0.0	5.4	0.0	20.0	0.0	0.0	0.0	0.0	0.0	0.0
37 Brook silverside Labidesthes sicculus	0.0	0.0	0.0	0.0	0.0	16.0	0.0	0.0	0.0	0.0	0.0	0.0
38 Smallmouth bass Micropterus dolomieui	0.0	3.0	4.0	73.8	10.2	14.0	3.4	14.0	2.0	0.0	2.0	66.0
39 Largemouth bass Micropterus salmoides	8.0	0.0	8.0	5.4	0.0	0.0	1.7	0.0	0.0	0.0	0.0	0.0
40 Green sunfish Lepomis cyanellus	6.0	6.0	8.0	36.0	0.0	10.0	15.3	24.0	12.0	0.0	0.0	0.0
41 Bluegill Lepomis macrochirus	26.0	0.0	24.0	23.4	1.7	18.0	0.0	0.0	0.0	0.0	0.0	4.0
42 Longear sunfish Lepomis megalotis	0.0	0.0	44.0	66.6	5.1	10.0	1.7	10.0	0.0	0.0	0.0	78.0
43 Rock bass Ambloplites rupestris	0.0	6.0	0.0	34.2	10.2	4.0	6.8	2.0	28.0	0.0	0.0	130.0
44 White crappie Pomoxis annularis	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0
45 Logperch Percina caprodes	4.0	0.0	0.0	0.0	0.0	10.0	0.0	0.0	0.0	0.0	0.0	0.0
46 Blackside darter Percina maculata	0.0	3.0	0.0	1.8	5.1	4.0	3.4	0.0	2.0	0.0	0.0	0.0
47 Slenderhead darter Percina phoxocephala	0.0	0.0	0.0	0.0	13.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
48 Fantail darter Etheostoma flabellare	0.0	0.0	0.0	1.8	18.7	6.0	0.0	0.0	0.0	14.0	6.0	12.0
49 Johnny darter Etheostoma nigrum	0.0	330.0	0.0	0.0	10.2	2.0	1.7	14.0	10.0	64.0	2.0	10.0
50 Orangethroat darter Etheostoma spectabile	0.0	0.0	0.0	9.0	0.0	16.0	0.0	6.0	0.0	4.0	26.0	18.0
51 Banded darter Etheostoma zonale	2.0	0.0	0.0	0.0	3.4	0.0	0.0	0.0	0.0	0.0	0.0	14.0
52 Freshwater drum Aplodinotus grunniens	8.0	0.0	0.0	0.0	0.0	0.0	1.7	0.0	0.0	0.0	0.0	0.0
Ammocoetes	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unidentified Centrarchidae	0.0	0.0	4.0	3.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unidentified Cyprinidae	0.0	0.0	4.0	12.6	6.8	0.0	5.1	0.0	16.0	0.0	0.0	0.0
Total number of Fish/Hour	214.0	2788.5	9224.0	1288.8	1766.3	746.0	323.0	1018.0	2118.0	2064.0	192.0	810.0
Total number of Species	24	23	24	34	33	34	27	22	20	16	10	22
Total number of Taxa (b)	24	24	26	36	34	34	28	22	21	16	10	22
Brillouin's Diversity (Base e) (b)	2.657	2.135	1.919	2.745	2.607	2.690	2.570	2.070	2.210	1.998	1.705	2.512
Brillouin's Evenness (Base e)	0.834	0.676	0.589	0.766	0.736	0.758	0.791	0.677	0.724	0.727	0.767	0.811

(a) ES/AC = (Electric Seine, A.C. Current)
(b) Includes ammocoetes, hybrids and unidentified categories

Table 3. Alternate Index of Biotic Integrity values for stations sampled in 1986 and 1987. Mackinaw River stations are in longitudinal order from downstream to upstream.

Stream	Station Code	1986	1987
Mackinaw River	DK-01	---	40
	DK-12	---	40
	DK-19	---	47
	DK-04	---	47
	DK-15	51	56
	DK-16	47	50
	DK-17	49	56
	DK-18	47	45
	DK-20	---	53
	DK-21	---	56
Hickory Grove Ditch	DKB-01	---	49
Little Mackinaw River	DKE-01	---	47
Mud Creek	DKG-01	---	45
Walnut Creek	DKJ-01	---	53
Panther Creek	DKK-01	36	53
	DKK-02	34	53
	DKK-02-A	---	42
West Br. Panther Creek	DKKB-01	---	49
East Br. Panther Creek	DKKC-02	---	49
Money Creek	DKP-02	---	34
Crooked Creek	DKT-01	---	34
Henline Creek	DKV-01	---	58

Table 4. Number of stations sampled and number of species collected in 1966, 1986 and 1987 from streams in the Mackinaw basin. Number of species is from all methods used at the station(s).

Stream	Stations[a]			Species[b]		
	1966	1986	1987	1966	1986	1987
Mackinaw River	5	5	10	44	45	51
Mud Creek	1	0	1	20	–	24
Walnut Creek	1	0	1	23	–	34
Panther Creek	1	2	3	27	17	45
W. Br. Panther Creek	1	0	1	20	–	20
E. Br. Panther Creek	1	0	1	1	–	22
Money Creek	1	0	1	19	–	16
Henline Creek	1	0	1	19	–	22
Crooked Creek	0	0	1	--	–	10
Hickory Grove Ditch	0	0	1	--	–	24
Little Mackinaw R.	0	0	1	--	–	23
Total	12	7	22	52	49	59

a Includes only streams sampled in 1987; additional streams were sampled in 1966.

b Excludes misc. minnows, hybrids, ammocoetes and unidentified taxa.

Table 5. Historical changes in species composition from three surveys of the Mackinaw River Basin.

Species found in 1966 and not found in 1987 (8 Species)

Common shiner (*Notropis cornutus*)
Creek chubsucker (*Erimyzon oblongus*)
Fathead minnow (*Pimephales promelas*)
Freckled madtom (*Noturus nocturnus*)
Goldfish (*Carassius auratus*)
Orangespotted sunfish (*Lepomis humilis*)
Tadpole madtom (*Notorus gyrinus*)
Yellow bass (*Morone mississippiensis*)

Species found in 1987 and not found in 1966 (15 Species)

American eel (*Anguilla rostrata*)
Black redhorse (*Moxostoma duquesnei*)
Black buffalo (*Ictiobus niger*)
Blacknose dace (*Rhinichthys atratulus*)
Blackstripe topminnow (*Fundulus olivaceus*)
Brook silverside (*Labidesthes sicculus*)
Logperch (*Percina caprodes*)
Pugnose minnow (*Notropis emiliae*)
Silver chub (*Hybopsis storieana*)
Silvery minnow (*Hybognathus nuchalis*)
Spotfin shiner (*Notropis spilopterus*)
Steelcolor shiner (*Notropis whipplei*)
Striped shiner (*Notropis chrysocephalus*)
Walleye (*Stizostedion vitreum*)
White Bass (*Morone chrysops*)

Species found in 1986 and not found in 1987 (3 Species)

Common shiner (*Notropis cornutus*)
Sauger (*Stizostedion canadense*)
Skipjack herring (*Alosa chrysochloris*)

Species found in 1987 and not found in 1986 (13 Species)

American eel (*Anguilla rostrata*)
Banded darter (*Etheostoma zonale*)
Black buffalo (*Ictiobus niger*)
Blacknose dace (*Rhinichthys atratulatus*)
Brook silverside (*Labidesthedes sicculus*)
Fantail darter (*Etheostoma flabellare*)
Pugnose minnow (*Notropis emiliae*)
Silver chub (*Hybopsis storeriana*)
Silvery minnow (*Hybognathus nuchalis*)
Steelcolor shiner (*Notropis whipplei*)
Walleye (*Stizostedion vitreum*)
White sucker (*Catostomus commersoni*)
Yellow bullhead (*Ictalurus natalis*)

Figure 1. Stations sampled during the 1987 Mackinaw River Basin fish investigation

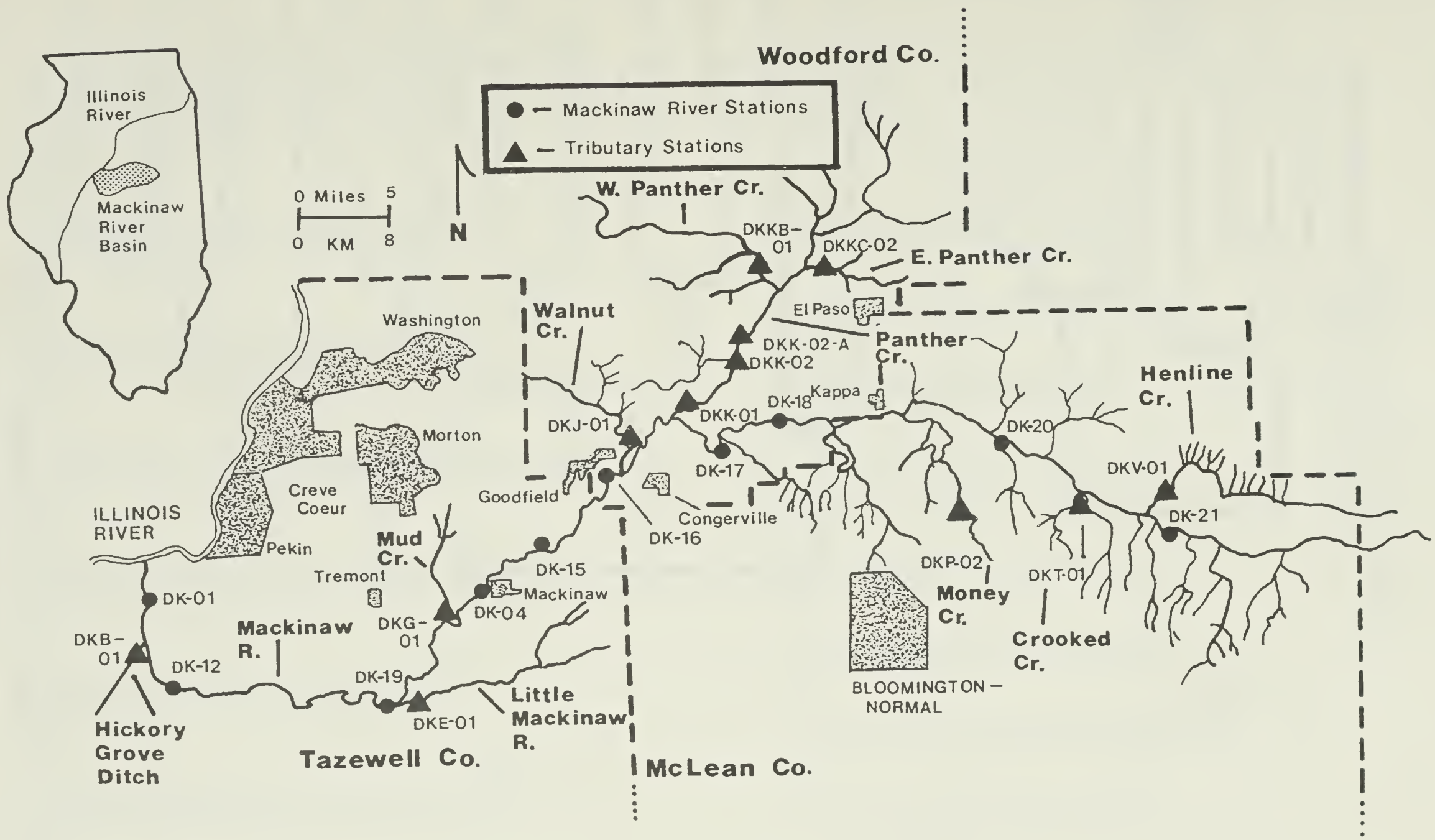


Figure 2. Coefficient of similarity based upon Horn's Index, using number of fish per hour.

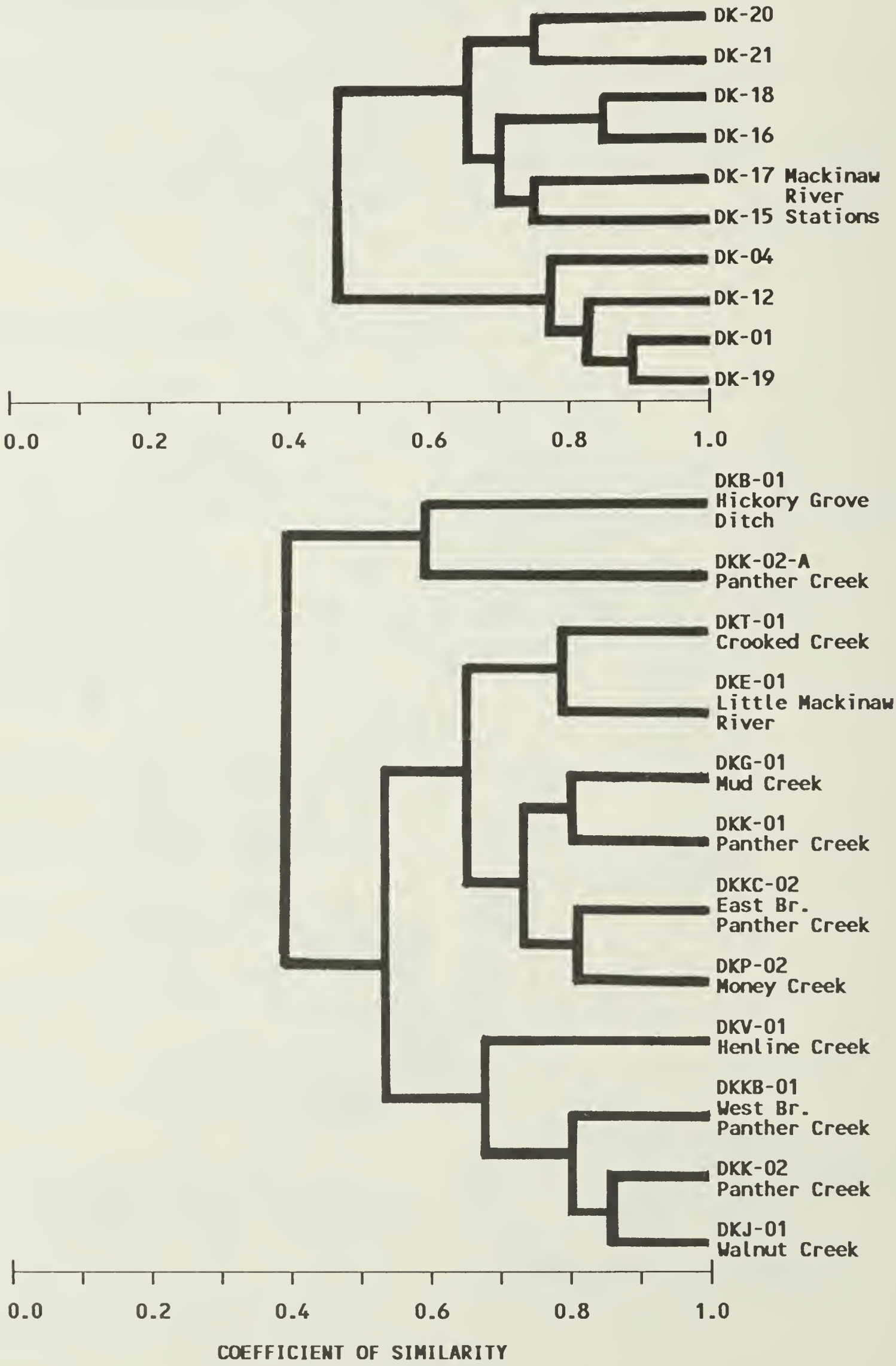
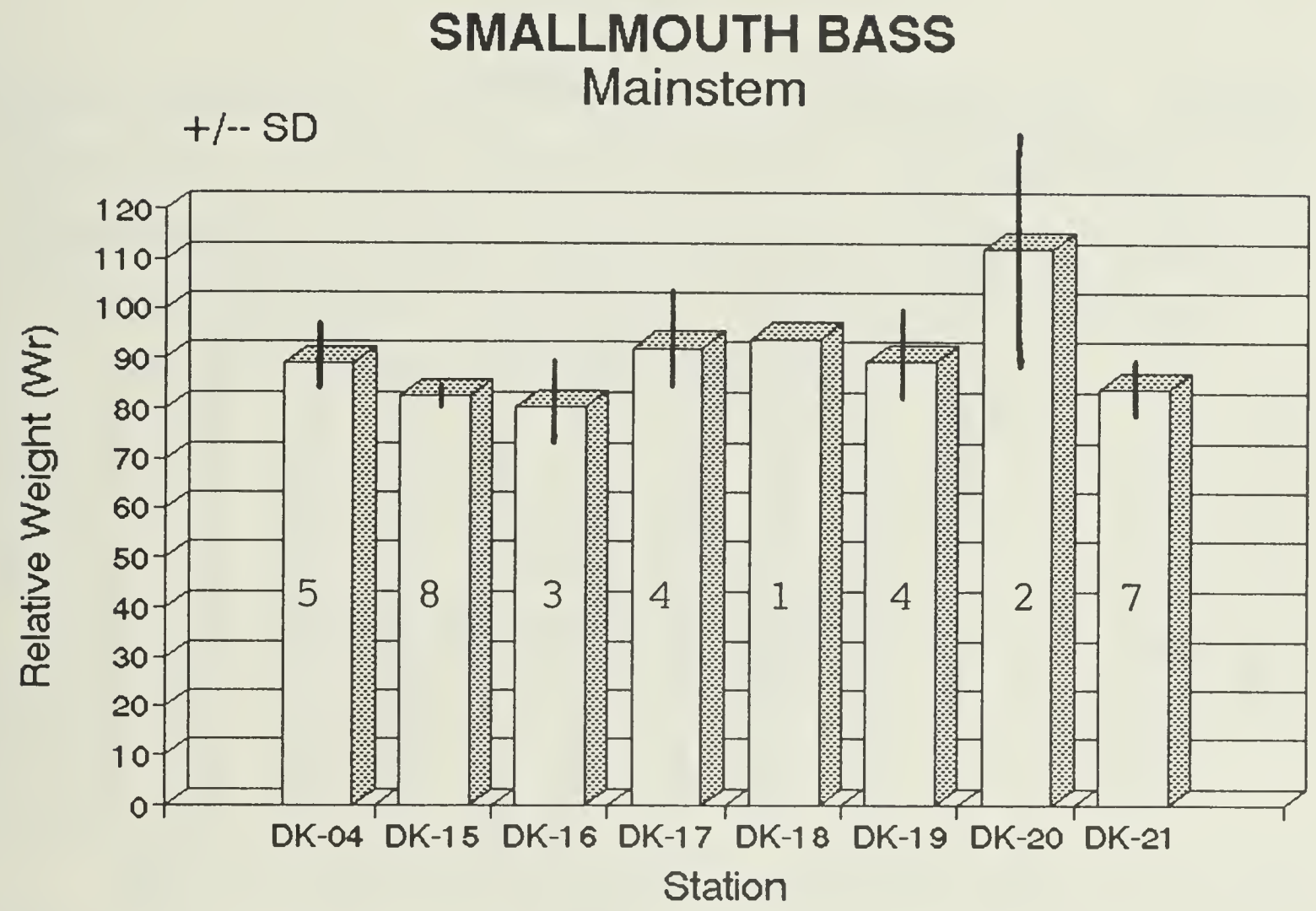


Figure 3. Relative weight (Wr) for smallmouth bass in the Mackinaw River Basin. Sample size is indicated within each bar.



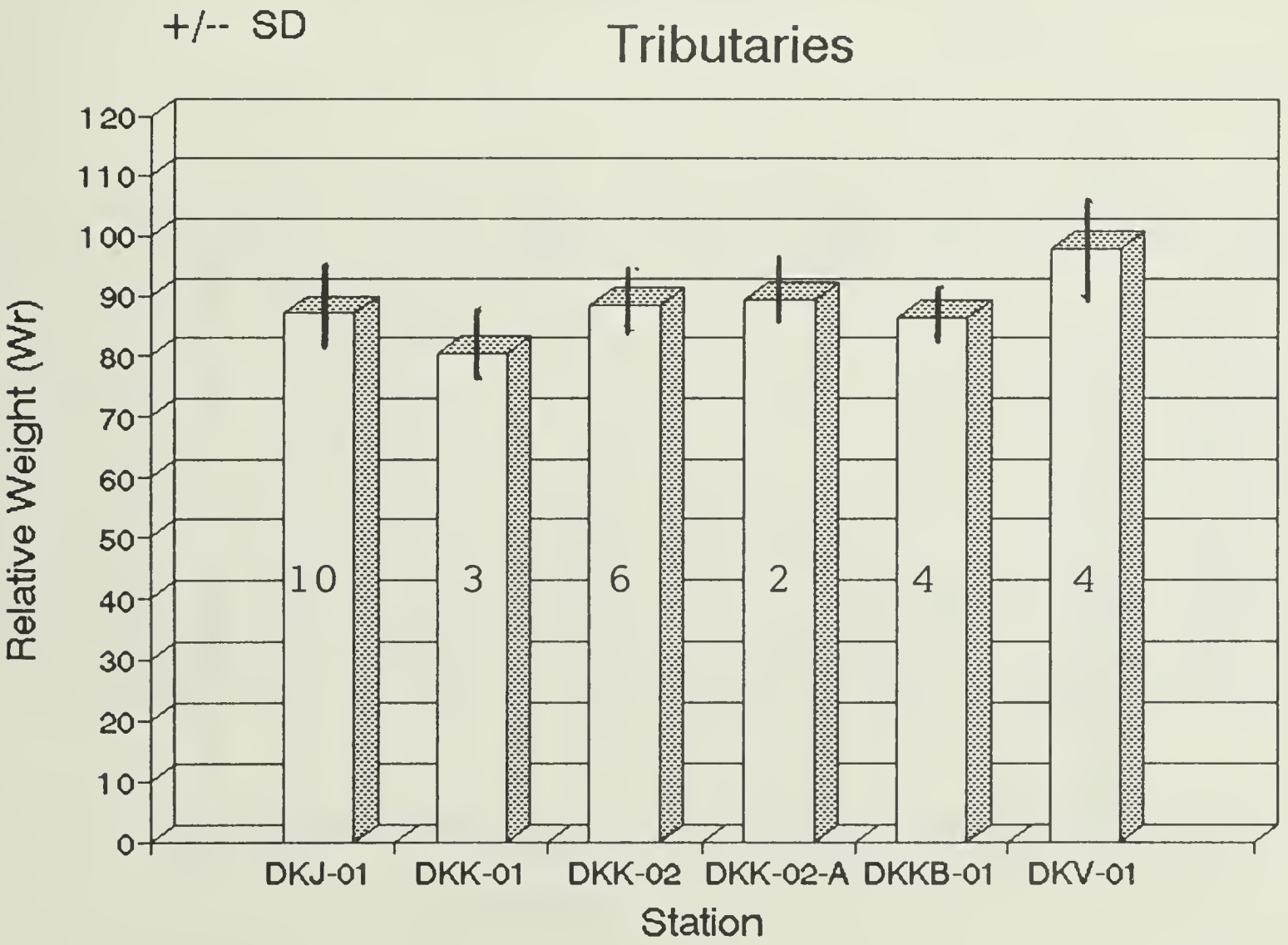
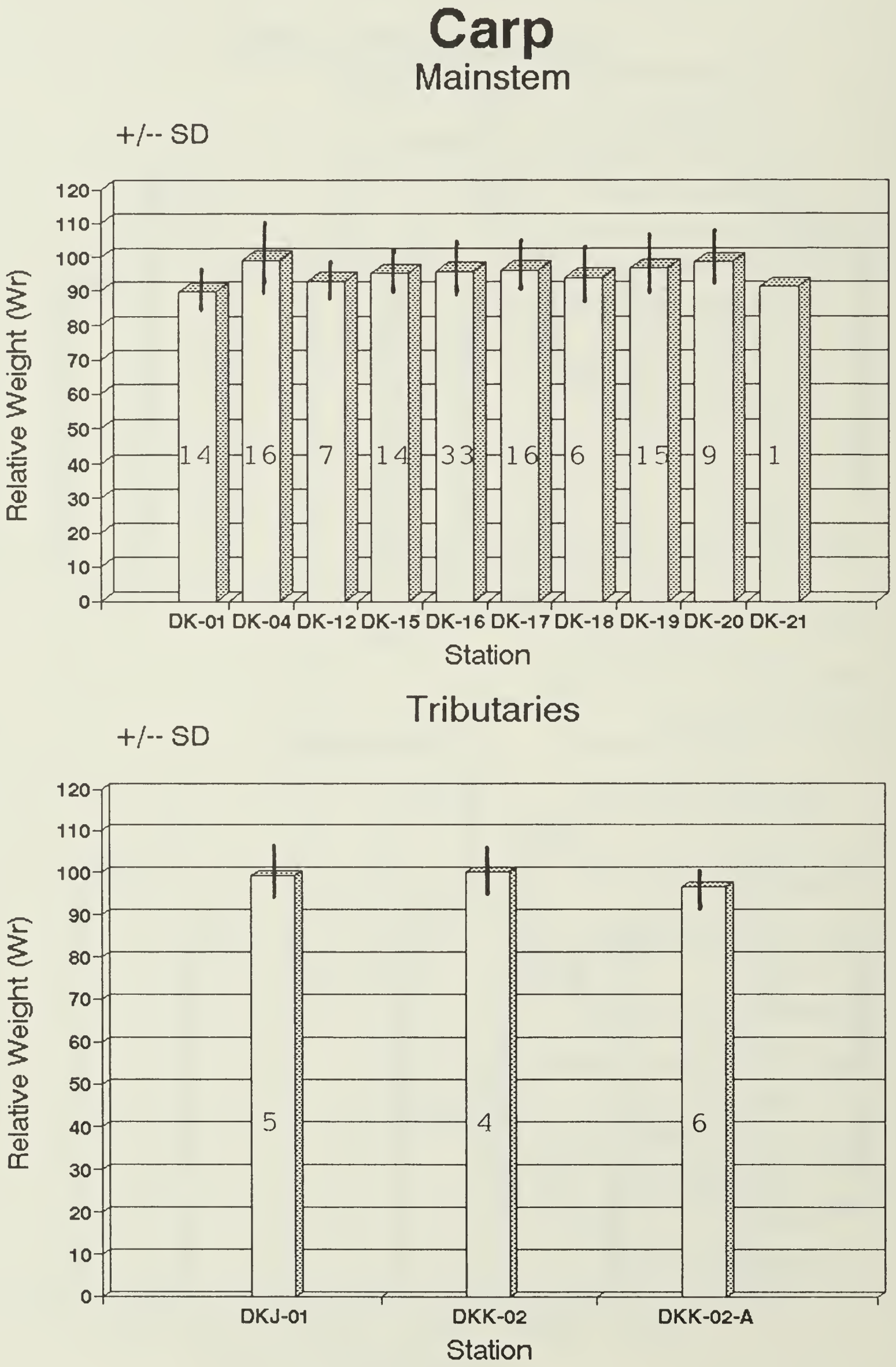


Figure 4. Relative weight (Wr) for carp in the Mackinaw River Basin. Sample size is indicated within each bar.



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Schrankiana schranki (Travassos, 1925) Strand, 1942 (Nematoda: Atractidae in *Leptodactylus mystaceus* (Spix, 1824) from Santa Cecilia, Napo Province, Ecuador

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ABSTRACT

One of five *Leptodactylus mystaceus* (Spix, 1824) collected from Santa Cecilia, Napo Province, Ecuador was infected with *Schrankiana schranki* (Travassos, 1925) Strand, 1942. This constitutes a new host record for this nematode.

INTRODUCTION

The geographic distribution of *Schrankiana schranki* (Travassos, 1925) Strand, 1942 has thus far been limited to leptodactylid anurans of South America and in particular Brazil and Ecuador. This nematode was first described from the large intestine of *Leptodactylus pentadactylus* (Laurenti, 1768) of Brazil by Travassos (1925) who named it *Schrankia schranki*. Strand (1942) noted that *Schrankia* was preoccupied and renamed it *Schrankiana*. Travassos (1949) inadvertently proposed the name *Schranknema*. The two genera are synonymous with *Schrankiana* Strand, 1942 having priority. It has since been reported in *L. pentadactylus* of Sao Paulo, Brazil by Freitas (1959) and subsequently in the same host of Napo Province, Ecuador by Dyer and Altig (1977). The present report is concerned with the detection of *S. schranki* in *Leptodactylus mystaceus* (Spix,1824) of Santa Cecilia, Napo Province, Ecuador.

MATERIALS AND METHODS

Five *Leptodactylus mystaceus* collected in Santa Cecilia, Napo Province, Ecuador were examined for helminths. Nematodes detected in the large intestine of one frog were fixed in hot glycerin-alcohol (nine parts 70% ethanol and one part glycerin) and cleared for study in glycerin. Representative specimens have been deposited in the Helminthological Collection of the Zoological Museum, Southern Illinois University at Carbondale, No. 121A.0.

RESULTS AND DISCUSSION

Several male and female specimens of *Schrankiana* Strand, 1924 were detected in the large intestine of one of five *Leptodactylus mystaceus* captured in Santa Cecilia, Napo Province, Ecuador. These agree with the description of *Schrankiana schranki* as given by Travassos (1925) and later by Freitas (1959).

Four additional species of *Schrankiana* have been reported from leptodactylid anurans. Freitas (1959) described *Schrankiana formosula* from *Leptodactylus fuscus* (Schneider, 1799) = (*L. typhonius* Boulenger 1882) of Itaguai, Rio de Janeiro, Brazil. *Schrankiana freitas* was described from the large intestine of *L. pentadactylus* of Exu, Pernambuco, Brazil by Baker (1982). *Schrankiana inconspicata* was described from *Leptodactylus labyrinthicus* (Spix, 1824) and *L. pentadactylus* of Salvador, Bahia (type locality); Salobra, Mato Grosso; Belo Horizonte, Minas Gerais; Pirassununga, Sao Paulo; and Cachimbo, Para, Brazil by Freitas (1959). *Schrankiana formosula*, *S. freitas*, and *S. inconspicata* have not subsequently been reported in anurans. *Schrankiana larvata* (Vaz, 1933) Fahel, 1952 was described from *L. pentadactylus* of Belo Horizonte, Minas Gerais and Pirassununca, Sao Paulo, Brazil. Subsequent reports include *Leptodactylus fuscus* [=*L. sibilatrix* (Weid, 1824)], *L. pentadactylus* and *L. labyrinthicus* of Salvador, Bahia; Urucum, Mato Grosso; and Cachimbo, Para, Brazil (Fahel 1952; Freitas 1959; Guimaraes et al. 1976). *Schrankiana schranki* is easily differentiated from other species in having large spicules.

The finding of *S. schranki* in *L. mystaceus* constitutes a new host record for this parasite. Reports of *Schrankiana* spp. in anurans thus far indicate that they are confined to frogs of the genus *Leptodactylus* and specifically to *L. pentadactylus*, *L. fuscus*, *L. labyrinthicus* and *L. mysticus* of South America. Since the geographic distribution of leptodactylid anurans includes Central America and the southern part of North America, hosts in these areas may also be infected with this nematode.

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White-Tailed Doe Tolerates Nursing By Non-Offspring

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ABSTRACT

A white-tailed doe (*Odocoileus virginianus*) allowed non-offspring fawns to nurse in the absence of her own offspring. It is speculated this behavior may represent a manifestation of individual inclusive fitness expressed primarily within clans of related females.

INTRODUCTION

White-tailed does are reported to be intolerant of suckling by non-offspring (Hirth 1985). "Thief suckling" (Espmark 1971) has been observed only in the presence of the doe's own fawns (Ozoga et al. 1982); when recognized by the doe, non-offspring were driven away (Hirth 1985). We report an incidence of nursing by non-offspring fawns in the absence of the doe's living offspring.

METHODS

We captured and marked Doe 212 (estimated age using tooth replacement and wear, 21 months) in Piatt County, Illinois, in March 1983. This doe was not seen with any fawns born in 1982 after marking and, considering her age, may not have bred as a fawn in fall 1981. If bred in fall 1981, she apparently had no surviving young by March 1983. This doe gave birth to 2 fawns that were captured and marked 2 June 1983. Doe 212 and the marked fawns were observed together (without other deer present) on two occasions after marking and before the observation reported here, and on 12 occasions (at times with other deer present) between August and December subsequent to this particular observation. When observed, Doe 212 was either alone or with the marked fawns on every occasion except that reported here. We did not observe Doe 212 to nurse either of the marked fawns on these occasions, but mutual grooming was frequently observed between her and the marked fawns.

RESULTS AND DISCUSSION

At 1920 CST 3 August 1983, Doe 212, an unmarked doe, and 2 unmarked fawns were observed feeding in a crop field. The unmarked doe appeared to be alone and paid no attention to the fawns. There was an unimpeded view for 75-100 m surrounding these deer and the marked fawns of Doe 212 were not close by. After a few minutes, both unmarked fawns approached Doe 212 from the side in the usual manner indicating a desire to nurse (rapid approach with head down and tail up and wagging). Both were allowed to suckle for about 30 seconds. They did not attempt to nurse again during the observation period of about 20 minutes. The duration of the nursing interval and the reaction of the doe to the strange fawns appeared similar to a typical nursing bout for a mother and her offspring.

Whitetails have been known to assume the care of orphans (Severinghaus 1949, Palmer 1951, McGinnes and Downing 1970) and thus might be expected to tolerate occasional nursing attempts by strange fawns. All reported attempts, however, have been concurrent with mother:offspring nursing. Such "thief suckling" behavior is common in some ungulates, including reindeer (*Rangifer tarandus*) (Espmark 1971), chital (*Axis axis)* (Schaller 1967), and several African antelopes (Dittrich 1968). The behavior is described as rare in elk (*Cervis canadensis*) (McCullough 1969), caribou (Lent 1974), and mule deer (*Odocoileus hemionus*) (Robinette et al. 1977, Griffith 1988). During a 5-year study of marked deer in eastcentral Illinois (several hundred observations of marked does and their fawns), we never again observed fawns to succeed in nursing from does other than their mothers. However, the opportunity for a newborn non-offspring to associate closely with does other than its mother is relatively uncommon in whitetails because their "hider" behavior precludes many such opportunities. In contrast, species whose young are "followers" associate with other females from birth (Lent 1974). Why Doe 212 nursed these fawns is unknown. She may have been familiar with them in view of the restricted ranges of does with fawns in summer and the considerable overlap in ranges that occurs among adjacent does in space if not in time (Ozoga et al. 1982). They may even

have been relatives as mother and daughter frequently establish ranges adjacent to one another (Ozoga et al. 1982, Nixon et al. 1989). Hamilton (1964) introduced the concept of inclusive fitness (an individual's own fitness plus its influence on the fitness of relatives) to describe such behavior as feeding and/or defending young born within the clan. The nursing of fawns related to Doe 212 would be consistent with this concept. This doe may also have been a primiparous breeder in 1983, and her maternal instincts may have been less well developed (in terms of acceptance of strange fawns) compared to those of older breeders (Ozoga and Verme 1986).

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Bioenergetics Of Canada Geese At Rend Lake, Illinois

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ABSTRACT

Time budgets, daily energy expenditures, and food availability were estimated for Canada geese (*Branta canadensis*) wintering at Rend Lake, Illinois during October-February, 1984-87. Activities varied ($P < 0.05$) among habitats, seasons, years, and time-of-day, whereas daily energy expenditures varied < 5% among seasons or years. Waste grain and forage within 16 km of Rend Lake Refuge exceeded the energy needs of an estimated 4 million days of goose use. However, refuge foods supplied < 50% of the energy needed during hunting seasons when geese restricted 99% of foraging activities to the refuge and lost an average of 312 g/bird of total body weight.

INTRODUCTION

The ability of birds to secure sufficient food resources to meet energy needs determines much of their life history (Kendeigh et al. 1977). Using time-activity studies in conjunction with caloric equivalents of activities, an energy budget can be estimated (Frederick and Klaas 1982, Reinecke and Krapu 1986, Tacha et al. 1987). Evaluation of available food energy and total energy required by a population can reveal how well an area supports a population. A negative energy balance has been associated with decreased over-winter survival of

waterfowl (Hepp et al. 1986, Perry et al. 1986); maintaining a positive energy balance among waterfowl is prudent.

Rend Lake Refuge is one of four southern Illinois areas providing most of the refuge wintering habitat for Canada geese of the Mississippi Valley Population. The dependency of geese on agricultural crops for food, relatively large wintering goose population (60,000-120,000), and small cropland area (315 ha) suggest that this refuge may not provide adequate food resources (Paine 1985). Our objectives were to estimate goose time and energy budgets, examine food availability on and off Rend Lake Refuge, and relate goose energy requirements to refuge food resources.

STUDY SITE AND METHODS

Rend Lake is a 7,650 ha impoundment of the Big Muddy River located in south central Illinois. Rend Lake Refuge comprises about 2025 ha of inviolate habitat (1410 ha lake, 315 ha cropland) on the northern portion of the lake. Paine (1985) and Pritchert (1988) described the study site in more detail.

Time budgets were calculated from diurnal and nocturnal behavioral observations and daily flight time estimates obtained October-February, 1984-87. Diurnal time allocations were estimated from instantaneous observations of flocks encountered along a survey route representative of available habitats, and nocturnal time allocations were estimated from data collected at roost sites (see Pritchert 1988). Daily flight time was determined from monitoring radio-marked geese two days per week from morning roost departure until evening roost return.

Diurnal time budgets were summarized for seven habitats (alfalfa/clover, corn, milo, soybean, wetland, winter wheat, and other), four seasons (Early Fall, Late Fall, Early Winter, and Late Winter), and 3 years (1984-85, 1985-86, and 1986-87). Daily flight data was summarized by season and year. Data were analyzed for significant variation ($P < 0.05$) using Analysis of Variance from the Statistical Analysis System (Ray et al. 1982); differences among means were identified using Tukey's Multiple Range Test.

Seasonal mean existence energy expenditures (EE) were estimated on the basis of goose body weights using Kendeigh et al. (1977:142-143) equations for nonpasserines at 30°C and 0°C for a 10-hour photoperiod. Time-budget data was converted to daily energy expenditures (DEE) using metabolic cost coefficients (MCC) for each activity (Frederick and Klaas 1982, Tacha et al. 1987). Proportion of time geese spent engaged in each activity was multiplied by the product of EE x MCC of that activity, and energy expenditures were summed to estimate seasonal DEE. Population energy requirements were estimated by multiplying goose-day-use (GDU) by DEE for that season. GDU was derived from weekly aerial survey data obtained from the Illinois Department of Conservation.

Goose weights (±10g measured with a spring scale) used to calculate EE were taken from specimens live-trapped and/or collected at the beginning of hunting season (October-November), shortly after hunting season (December), and just prior to spring migration (February). Weights were adjusted to reflect the

same age and sex ratios in each collection period; these standardized age and sex ratios, (representative of the population of geese at Rend Lake) were derived from the average of trapped samples and Spitzkiet (1984), respectively.

Food availability was estimated using cropland records obtained from county Agricultural Stabilization and Conservation Service offices for an area within 16 km of Rend Lake Refuge. Grainfields were sampled to quantify waste grain availability immediately after harvest and after goose departure in spring during 1984-87 (Pritchert 1988). An additional sample was collected at the end of goose hunting season in December 1986. Forage fields were sampled during each season in 1986-87. Samples were oven dried and weighed to the nearest 0.1g. Dry weights were used to estimate kg/ha food available on and within 16 km of the refuge. Apparent metabolizable energy of foods were calculated from published values (Bushbaum et al. 1986, Fredrick et al. 1987).

RESULTS AND DISCUSSION

Time and Energy Budgets

Habitat, season, and year explained about 60% of the variation in diurnal goose activities. Activities differed more by habitat than any other variable. Rest, locomotion, and comfort totaled 86% of activities in wetlands, while feed, rest, and alert made up 89% of activities in uplands. Percentage of time allocated to alert and feed were highest and locomotion and rest were lowest in Early Fall (Table 1). Conversely, resting was highest in Early Winter when alert and feed were lowest. Foraging activity increased 43% in 1986-87 over that observed in 1984-85, while resting declined 57% between those years.

Rest comprised 95% of nocturnal activities, while comfort, locomotion, and alert made up the remaining 5%. Flight comprised a consistent 1% of diurnal activities.

Diurnal, nocturnal, and daily flight activities were combined into a 24-hour (diel) time budget (Pritchert 1988). About 70% of diel time was spent resting, 13% feeding, 8% engaged in locomotor activities, 4% comfort, 4% alert, and 1% in other activities.

Activities differed among seasons and years in direct response to changes in habitat use as reported by others (Pritchert 1988, Caithamer 1989). Wetlands were used as resting areas because they provide security from predators (Raveling et al. 1972). Resting was also the primary activity during nocturnal periods; however, it was not the only night activity as has been assumed by other authors (Fredrick and Klaas 1982).

Overall mean weights of geese were 3,545 g in 1984-85, 3,433 g in 1985-86, and 3,457 g in 1986-87. Comparison of weights taken at beginning and end of hunting revealed declines of 13% and 4% during October-December in 1985 and 1986, respectively. Weights obtained in December-February showed increase of 6% in 1985-86 and 4% in 1986-87.

Existence energy was highest in Early Winter (Table 2), 14% higher than observed in Early Fall. Conversely, MCC for daily activities declined 12% during the same period (Pritchert 1988). However, daily energy expenditures varied < 5% among seasons or years.

Walsberg (1983) suggested avian existence energy expenditures are completely obligatory and influence productive energy expenditures (activities); results from this study support his theory. Seasonal energy budgets indicated EE increased as temperatures declined through Late Fall and Early Winter (Table 2). Geese responded to increased EE demands by engaging in less costly activities (e.g., rest) to reduce productive energy expenditures.

Energy Needs and Availability

Aerial surveys suggested about 4 million GDU per year for the Rend Lake area during October-February, 1984-87 (Table 2). Population levels peaked near 60,000 geese during Early Winter. Population energy expenditures were an estimated 2.1 billion kcal per year.

Waste corn on and within 16km of Rend Lake refuge averaged 139 kg/ha immediately after harvest and ranged from a low of 122 kg/ha in 1984-85 to 158 kg/ha in 1985-86 (Pritchert 1988). Soybean totals were 233 kg/ha in 1985-86 and 119 kg/ha in 1986-87. An additional 2,280 kg/ha of green forage was provided by forage foods (alfalfa/clover and winter wheat).

Forage represented about 58% of the total energy available to geese in 1986-87 (Table 3). Corn provided 24% and soybeans the remaining 18%. Total forage declined 82%, corn 87%, and soybean 96% by time geese departed in spring (Pritchert 1988).

Available metabolizable energy within 16km of Rend Lake Refuge, as calculated from 1986-87 food availability data totaled about 29 billion kcal (Table 3). This exceeded population energy requirements (2.1 billion kcal) needed for geese to maintain body weight through winter.

Although adequate energy was available within 16km, the refuge was unable to support geese in a positive energy balance during hunting. About 99% of the geese observed during each hunting season were on the refuge (Pritchert 1988). The refuge supplied only 34% of energy required by geese during the 1986 hunting season (Table 4). Assuming forage availability (kg/ha) was equal between years, the refuge supplied about 41% and 42% of the energy needed during the 1984 and 1985 hunting seasons, respectively.

Refuge crops were harvested prior to hunting in 1986, making about 290 million kcal of metabolizable energy available on Rend Lake Refuge. Geese lost weight during the 1986 hunting season, despite reductions in productive energy expenditures, because refuge foods provided only a third of the energy needed for geese to maintain body weight.

Crop harvest chronology on the refuge could be in part responsible for a negative energy balance observed in 1985. During that year, harvest did not occur until hunting was almost over. Although geese further reduced energy-costly activities, weight loss was over 3 times that observed in 1986.

CONCLUSIONS AND RECOMMENDATIONS

Rend Lake Refuge could not support the energy needs of Canada geese when they were restricted to the refuge during hunting. If management

goals are to maintain birds in good physical condition in an effort to increase over winter survival and/or reduce possible declines in subsequent productivity, then adequate food resources must be available to meet population needs during hunting. To insure this it may be necessary to increase refuge cropland or modify refuge farming practices to provide needed foods.

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Table 1. Percentage diurnal time allocations and the habitats and seasons with the highest percentages of each goose activity. Data are from observations of 1,958 flocks of Canada geese at Rend Lake, Illinois, October-February, 1984-87.

Activity	Percent Time	Habitat High	Seasonal High
Alert	8	Corn/Milo	Early Fall
Comfort	6	Wetland	Late Fall
Feed	31	Alfalfa/Clover	Early Fall
Locomotion	15	Wetland	Late Fall
Rest	39	Wetland	Early Winter
Other	1	---	---
Total	100	---	---

Table 2. Mean seasonal existence and daily energy expenditures, goose-day-use, and population energy requirements of Canada geese using Rend Lake, Illinois, October-February, 1984-87.

Season	Existence Energy (kcal/bird/day)	Energy Expenditures (kcal/bird/day)	Goose-Day-Use (x 1000)	Population Energy Needs (mill kcal)
Early Fall	273	469	148	70.7
Late Fall	308	490	341	166.3
Early Winter	318	479	2087	976.6
Late Winter	317	496	1524	764.9

Table 3. Food available on and within 16 km of Rend Lake Refuge during fall, 1986.

Habitat	Hectares	kg/ha	Metabolizable Energy (kcal/kg)	Available Energy (mill kcal)
Corn	12,995	137	3,960	7,050
Soybean	12,683	119	3,660	5,224
Wheat	7,533	235	1,220	2,160
Alfalfa/Clover	5,839	2,047	1,240	14,821
Total				29,255

Table 4. Available food energy and goose energy requirements of Rend Lake Refuge during the 1984-86 hunting seasons.

Year	Goose Day-Use (x 1000)	Population Energy Needs (mill kcal)	Available Energy (mill kcal)	Percent Weight Loss
1984	288	110	46	---
1985	996	513	212[a]	13
1986	1,665	854	288	4

[a] Grain crops were harvested during last week of goose hunting.

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The First Records of Three Fish Species in Illinois Waters of Lake Michigan: Longear Sunfish (*Lepomis megalotis peltastes*), Black Crappie (*Pomoxis nigromaculatus*), and the Channel Catfish (*Ictalurus punctatus*)

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ABSTRACT

Two individuals of longear sunfish were captured by electro-shocking at Jackson Park Harbor on August 10, 1989. This is the first record of the species in Illinois waters of Lake Michigan. The total lengths and weights of the specimens were 9.7 cm (19 g) and 10.1 cm (13 g). Another longear sunfish was captured at Belmont Harbor on August 21, 1989. The northern subspecies, *Lepomis megalotis peltastes*, was known previously only from Kankakee, Will, Grundy, and Iroquois counties and was considered rare in these counties (Smith, 1979). None of the counties border Lake Michigan. The southern subspecies, *Lepomis megalotis megalotis*, occurs in the southern and central portions of Illinois.

The species was believed to have been extirpated in the Illinois portion of the Lake Michigan drainage basin (Becker, 1976), since the only previous specimen (INHS 84578) in this portion of the drainage was captured on June, 1880 in the Calumet River, south of Chicago (Smith, 1979). The longear sunfish has been found in the Milwaukee and Green Bay areas but not in Lake Michigan (Becker, 1976). In Wisconsin, the longear sunfish is considered a threatened species, and, while the longear sunfish is common in Michigan and Indiana (Becker, 1976), there are no reports of the species captured along the Lake Michigan coasts of these states (Becker, 1976).

A specimen of the black crappie (*Pomoxis nigromaculatus*) was captured by electro-shocking in Belmont Harbor in Chicago, Illinois on August 21, 1989

and is the first record for Illinois waters of Lake Michigan. The total length of the fish was 16.2 cm and it weighed 65.0 g. There are some records (pre-1908) of black crappie occurring south of Chicago in the Lake Michigan drainage, but none has been reported from the Illinois waters of Lake Michigan (Smith, 1979). The black crappie occurs throughout Illinois but is less common than the white crappie (*Pomoxis annularis*). The only specimens of black crappies previously collected in Lake Michigan were captured in Green Bay in Wisconsin (Becker, 1976).

This is the first record of the channel catfish in Illinois waters of Lake Michigan. The fish was caught by hook and line at Diversey Harbor in Chicago, Illinois, on August 18, 1989. The total length of the fish was 41.5 cm and it weighed 538 g. The channel catfish occurs throughout Illinois, but there are few records of this species in northeastern Illinois (Smith, 1979). There are no reports of the species in the Illinois portion of the Lake Michigan basin (Becker, 1976; Smith 1979). Channel catfish occur in the Wisconsin and Indiana portions of the drainage basin but the only other specimens from Lake Michigan were captured in the southwestern portion of Green Bay in Wisconsin (Becker, 1976).

ACKNOWLEDGEMENTS

We thank Dr. Lawrence Page for confirming the identification of the specimens; they now reside in the fish collection at the Illinois Natural History Survey at Champaign, Illinois. They are catalogued as follows: longear sunfish from Jackson Park (INHS 65045), black crappie (INHS 65044), and channel catfish (INHS 65043). The collection of the specimens was part of a project sponsored by the Illinois Department of Conservation, F-93-R.

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A Tribute To Philip W. Smith

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Philip W. Smith was a life-long friend, and his knowledge of herptiles and fishes of Illinois was unexcelled. He was a naturalist of high repute, having spent many decades conducting fieldwork in Illinois, the southwestern United States, and Mexico.

Philip W. Smith, known as 'Phil', passed away on Saturday, 11 October 1986, after a bout with cancer. He was born near Neoga, Illinois on 2 December 1921, the son of Ward and Pauline Brown Smith. His family moved often, and he attended grammar school in several communities in southcentral Illinois.

Early in his childhood he became an abiding naturalist interested in birds and entomology, and shifted to herpetology by the young age of 16 years. It was during this period that he met his future wife, Dorothy M. Dearnbarger.

In 1940 Phil started his college education at Eastern Illinois Teachers College at Charleston, working as a section hand for the Pennsylvania Railroad during the summer months. In 1942 he went to work at Ridge Lake Field Laboratory near Charleston, and this began his close relationship with the Illinois Natural History Survey.

On May 23, 1942 Phil and Dorothy were married in Shelbyville, Illinois. Shortly thereafter Phil was inducted into the Army, and served until his discharge in December of 1945. After his discharge he immediately returned to school at Eastern.

In June of 1947 Phil became Junior Scientific and Technical Assistant for the Illinois Natural History Survey and served in this capacity until 1952. It was during this period that Phil published his first papers on the reptiles and amphibians of eastcentral Illinois. It was also during this period that Phil came under the guidance of Hobart M. Smith at the University of Illinois. Phil completed his BS Degree in February of 1948, and his MS Degree in September of 1949, under the supervision of Hobart M. Smith and other distinguished University of Illinois scientists, Victor Shelford, Charles Kendeigh and Harley Van Cleave. After completion of his PhD in June 1953, Phil was hired by Herbert H. Ross as Assistant Taxonomist in the Section of Faunistic Surveys & Insect

Identification at the Illinois Natural History Survey. His last decade with the Survey consisted mainly of administrative duties while holding the position as Head of the Section of Faunistic Surveys and Insect Identification. Phil also served as Professor of Zoology at the University of Illinois from 1965 until 1979.

Phil was gracious and friendly, always generous in helping others. He was a prolific worker in a extraordinarily broad range of both herp and fish subjects relating to systematics, animal behavior, evolution and ecology. He was Editor-in-Chief of COPEIA in 1959, and Vice President of the American Society of Ichthyologists and Herpetologists (ASIH) in 1966. Phil also served on the ASIH Board of Governors for three separate terms (1958-1976) and on the ASIH Long-Range Planning Committee from 1971-1974. He was President of the Herpetologists League for both 1966 and 1967, and for that society also served on the Executive Council and Editorial Boards of its journal HERPETOLOGICA. In August of 1986, he was awarded an honorary Doctor of Science degree from Eastern Illinois University.

Phil made numerous contributions to the field of herpetology; in fact, he published more than 20 papers as a graduate student. His monumental work, the "Amphibians and Reptiles of Illinois" appeared in 1961. Phil changed fields from herpetology to Ichthyology, and his book "The Fishes of Illinois" appeared in 1979. For 39 years he published over 100 scholarly journal articles on fishes, amphibians, reptiles, and bats. His last work was a book, "A Naturalist in the Environmental Crisis," which traces his life from childhood through his professional career. His lifelong love of nature and high respect for preservation of our vastly dwindling wildlife is reflected in this highly interesting book. Anyone interested in nature or having associated with Phil and Dorothy will find this book a must for their library.

On December 2, 1986, Dorothy received a letter of condolences from Michael J. Madigan, Speaker of the House of Representatives for the state of Illinois. Phil is survived by his wife Dorothy, daughter April, and two grandchildren, Suzanne and Langston Hoffman. Many of us lost a good friend, and the herpetological and ichthylogical communities have lost a true professional.

The following is a complete list of the scientific publications of Philip W. Smith.

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Philip W. Smith 1979

Academy Notes

The next Annual Meeting of the Illinois State Academy of Science will be held on October 26-27, 1990. This 83rd Annual Meeting will be held on the University of Illinois, Urbana campus. The meeting will be co-sponsored by the Natural History Survey and the University of Illinois, Urbana.

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Transactions of the Illinois State Academy of Science
(1990), Volume 83, 3 and 4, pp. 126-27

A Recent Collection in Illinois of *Megalodonta beckii* (Torr.) Greene

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College of Lake County
Grayslake, Illinois 60030

ABSTRACT

The water marigold, *Megalodonta beckii* (Torr.) Greene (*Bidens beckii* Torr.) was last reported in Illinois in Grays Lake, Lake County, in 1966 and previously in 1898. It was collected again on August 25, 1988 in Cedar Lake, Lake Villa, Lake County.

FINDINGS

A rare submersed aquatic plant, *Megalodonta beckii* (Torr.) Greene (Asteraceae) was last found in Grays Lake, Lake County, Illinois by Benjamin L. Dolbeare, of the Illinois State Museum, on August 4, l966 (Dolbeare 1967). The plant bed was later covered with sand fill to extend the Grays Lake village beach and the only known population in Illinois was apparently lost.

During the drought of 1988, the author discovered *Megalodonta beckii* in the south bay of Cedar Lake, 16 km north of Grays Lake. While rare in Illinois, the water marigold is found in Wisconsin lakes, the nearest in Rock Lake, Kenosha County (Swink and Wilhelm, 1979).

The collection reported here had yellow ray and disk flowers in a single head which was above the water surface of one meter depth. After two years of normal rainfall, Cedar Lake had resumed its former level and the plants flowered 15-25 cm below the surface. Collection data for the specimen which has been deposited at the Illinois State Museum herbarium are: Cedar Lake, Lake County, Illinois, August 25, 1988, Linda Curtis.

Associates which are on the State Endangered and Threatened Plant Checklist (IESPB 1990) are *Potamogeton gramineus* L., *P. praelongus* Wulfen, *P. strictifolius* Benn., and *P. robbinsii* Oakes. Aquatic associates not on the list are *P. zosteriformis* Fern., *P. richardsonii* (Ar.Benn.) Rydb., *P. pectinatus* L., *Vallisneria americana* Michx., *Myriophyllum exalbescens* Fern., and *M. spicatum* L. Others in Cedar Lake are *Chara, Ceratophyllum demersum* L., *Elodea nuttallii*

(Planch.) St. John, *Heteranthera dubia* (Jacq.) MacM., *Potamogeton amplifolius* Tuckerm., *P. crispus* L.,*P. illinoensis* Morong, *P. natans* L., *P. nodosus* Poir., *P. pusillus* L., *Najas flexilis* (Willd.) Rostk. & Schmidt, *N. guadalupensis* (Spreng.) Magnus, *N. marina* L., *Nuphar variegatum* Engelm., *Nymphaea tuberosa* Paine, *Pontederia cordata* L., *Ranunculus longirostris* Godr. and *Utricularia vulgaris* L.

Cedar Lake is a natural glacial lake in the Fox River basin. The Illinois E.P.A. study (IEPA 1979) classified it as a Group 3 lake of good conditions and low problem potential. Cedar Lake's maximum depth is 12 meters, the average depth is three meters with a surface of 115 ha.

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(1990), Volume 83, 3 and 4, pp. 128-48

Growth and Water Use Efficiency of *Quercus alba, Q. bicolor, Q. imbricaria* and *Q. palustris* Seedlings Under Conditions of Reduced Soil Water Availability and Solar Irradiance

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ABSTRACT

Growth and water use efficiency were determined for 2-year-old white oak (*Quercus alba*), swamp white oak (*Q. bicolor*), shingle oak (*Q. imbricaria*) and pin oak (*Q. palustris*) seedlings grown under three shade treatments (30, 55, and 73%) and two irrigation regimes (container capacity and mild drought). With species and water regimes combined, the dry weight increment, root, stem, leaf, shoot dry weight and water use efficiency of the oaks decreased significantly as shade level increased from 30 to 73%. Shade had no effect on height increment, while shoot/root dry weight ratio increased with increasing shade. White oak and swamp white oak closely followed this overall pattern, but the only response shingle oak and pin oak exhibited to increasing shade levels was an increase in shoot/root ratio of 24 and 26%, respectively.

With species and shade levels combined, experimentally imposed drought reduced the oak seedling dry weight increment, root, leaf, and shoot dry weights, caliper increment and water use efficiency. The drought treatment had no effect on seedling height increment, but increased the shoot/root dry weight ratio. Under the drought regime, white oak and shingle oak had the highest water use efficiency values (1.65 and 1.73 mg cm^{-3}) compared with values of 1.46 mg cm^{-3} for pin oak and 1.01 mg cm^{-3} for swamp white oak. White oak and shingle

oak also had the lowest shoot/root ratios (0.60 and 0.87) when compared with pin oak (0.96) and swamp white oak (1.08).

Upland white oak and shingle oak seedlings had the lowest specific leaf areas (158.7and 157.7 cm^2/g) while the bottomland pin oak (176.1 cm^2/g) and swamp white oak (174.8 cm^2/g) had the highest. Pin oak and shingle oak seedlings flushed more times (2.5 and 1.9) during the growing season than swamp white oak (1.6) and white oak (1.0). Drought reduced the number of flushes of all the tested oak species with the exception of white oak, while shade had no detectable effect on oak seedling flushing.

INTRODUCTION

The effects of shade on growth and development of oak seedlings have been examined in numerous studies by growing seedlings under shadecloth or similarly altering radiation levels (Shirley 1929, McGee 1968, Loach 1969, Musselman and Gatherum 1969, Phares 1971, Farmer 1975, Johnson 1984, Gottschalk 1985). The results of these studies have sometimes been inconsistent with one another. For example, in some cases height growth increased with increasing shade (Shirley 1929, Musselman and Gatherum 1969), in other cases it decreased with shade (McGee 1968, Johnson 1984). Others studies indicated that shade had no effect on oak height growth (Farmer 1975) or that peak growth occurred at intermediate irradiance levels with height decreases in both directions (Phares 1971, Shirley 1929). One reason for such inconsistencies may be the use of first year seedlings in most of these studies. Early survival and growth of oak seedlings are strongly influenced by the stored carbon and nutrient reserves of the hypocotyledons (Crow 1988). However, once seedlings establish root systems adequate for supplying water and nutrients to the plant, increased irradiance levels will usually result in increased growth rates. Another factor not considered in many of these studies is the possibility of interaction between irradiance and soil moisture. Together with shade, competition for water and nutrients in the understory of forest stands with an abundance of dominant tree roots in surficial soil can reduce seedling growth (Carvell and Tryon 1961, Ferrell 1953). Oak seedlings benefit from light shade because it moderates temperatures and water use (Kramer and Kozlowski 1979). Exposure to full solar irradiance can induce severe water stress in plants, especially during times of drought. Root growth of northern red oak (*Quercus rubra* L.) is particularly sensitive to even moderate drought. Red oak seedlings subject to various degrees of drought did not regenerate new roots at -0.6 MPa (-6 bars) (Larson and Whitmore 1970). However, white oak roots have been reported to be able to continue growth when the surrounding soil water potential was -1.2 MPa (Teskey et al. 1978). Farmer (1980) found that white oak seedlings have lower shoot/root ratios than northern red oak and it has been reported that white oak also has a deeper root system than northern red oak (Stout 1968, Hinckley et al. 1980).

Few studies of any oak species have examined the combined effects of shading and drought on growth and water use of seedlings (Gatherum et al. 1963, Musselman and Gatherum 1969). Consequently growth and water use of

four oak species under varying shade and soil moisture conditions were examined in this study. Two of the oak species studied belong to the subgenus Leucobalanus, the white oaks [swamp white oak (*Quercus bicolor* Willd.) and white oak (*Q. alba* L.)] and two belong to the subgenus Erythrobalanus, the red oaks which include pin oak (*Q. palustris* Muenchh.) and shingle oak (*Q. imbricaria* Michx.) (Harlow et al. 1979). Within each subgenus a bottomland species (swamp white oak and pin oak) and an upland species (white oak and shingle oak) were included in this study. Shingle oak and swamp white oak were selected because they have been little studied to date.

Because various silvicultural methods call for the reduction of overstory canopy to stimulate oak reproduction, there is a need to determine more precisely which irradiance levels provide the best survival and growth conditions for seedlings of a given oak species. Since competition by roots for soil moisture is often severe in the understory of forest stands, and since this competition also limits the ability of plants to tolerate understory conditions, this study was designed to determine the combined effects of reduced irradiance and soil moisture on growth and development of oak seedlings. The objectives of this study were to determine if there are differences in growth and water use efficiency (mg/cm^{-3}) within each oak species among three shade levels and two soil water regimes and to determine if differences are associated with oak species, oak subgenus, or ecological niche of a species.

METHODS

The study was conducted during the summer of 1989 in a greenhouse constructed with iron-free glass located at the University of Illinois in Urbana-Champaign. Iron-free glass allows penetration of solar radiation of a spectral quality more similar to natural radiation in comparison with the glass normally used in greenhouses. Temperatures in the greenhouse ranged from 23-26°C during the day and 20-23°C during the night. The seedlings were grown under natural light and photoperiod between May 22 and October 16. One hundred 2-0 bare-root dormant seedlings each of white oak, swamp white oak, pin oak, and shingle oak were obtained from commercial nurseries in the midwestern U. S. All seedlings were in the 15-30 cm shoot height class, with the exception of white oaks which ranged from 30-46 cm in shoot height. The seedlings were measured for initial stem height and caliper (diameter) at 1 cm above the root collar and then planted in a steam pasteurized 1:1:1 fertile loamy soil: perlite: sphagnum peat moss mixture (pH of 5.5) in 60 cm tall by 10 cm diameter cylindrical pots. The pH did not change appreciably during the course of this study. No fertilizers were added to the soil mixture. The initial fresh weights of all seedlings and pot weights were determined. In each pot, a seedling was planted in 2.6 kg of the air dry soil mixture. The seedlings then were watered daily with tap water and allowed to break bud and grow for five weeks. After five weeks, 30 seedlings of white oak, 25 seedlings of swamp white oak, and 20 seedlings of pin oak and shingle oak (unequal replicates due to mortality) were placed under each of three shade tents with advertised shade values of 30%, 55%, and 73% of incident light. The advertised shade percentages of these tents were found to

correspond exactly with the percentage reductions in photosynthetically active radiation (PAR) (±1%) measured with a Li-Cor Integrating Photometer at noon and 4 p.m. (Model LI-188B with quantum sensor, Li Cor Inc., Lincoln, Nebraska). The shade tents were 1.33 m wide x 1.67 m long and had 1.33 m walls on each of four sides. An additional three seedlings per species were destructively measured to obtain an estimate of total, root, stem, leaf and shoot (sum of leaf and stem) fresh and dry mass. These ratios of initial dry weight to fresh weight measurements were used to obtain a value of seedling dry weight at this stage of the study. Dry weight increments were estimated by difference from the dry seedling weights at the end of the study. The proportions of dry to fresh weight obtained for the three seedlings per species were highly consistent, differing by no more than 5% in any case. The estimated initial dry weight means and standard deviations were 33.34 ± 9.76 g for white oak, 8.13 ± 2.20 g for swamp white oak, 7.48 ± 3.33 g for shingle oak, and 7.51 ± 1.82 g for pin oak seedlings.

The seedlings were grown for 2-3 weeks with regular watering to allow them to acclimate to the shade. Then all pots were watered to the drip point, allowed to drain for 24 h, and weighed to determine container water capacity, (the difference between total pot weight 24 h after watering and the sum of container, dry soil mixture, and initial plant fresh weights). Half of the seedlings of each species under each shade treatment were maintained at 90-95% of container water capacity while the remaining seedlings had drought imposed by withholding watering.

Three pots with seedlings maintained at container water capacity for each shade and species combination were sampled randomly every 2-5 days and weighed to monitor the water lost from the pots. All pots were then watered accordingly to restore container-capacity weight and the amount of water added at each watering was recorded. Three pots without seedlings for each shade treatment and watering regime were mixed in with the other seedling pots, weighed, and watered periodically in the same manner as the respective pots containing seedlings in order to estimate pot evaporation. Water use for each plant between bimonthly weighings was calculated as the change from initial weight of watered pots containing seedlings plus the amount of water added during the interval minus the water loss of the corresponding check pots lacking seedlings. The water in the system due to increasing seedling weight was not considered because it constituted an insignificant proportion of transpired water.

The dry weights of seedlings at the beginning of the treatment period were estimated by destructively sampling a second set of three seedlings of each species just prior to treatment initiation. Initial estimated dry weights of seedlings were increased according to mean proportionate increase in dry weight calculated for the samples of the respective oak species. The proportionate increase in dry weight for a species did not vary by more than 4% from the mean proportion. A change in whole plant dry weight for the final two-month treatment period was estimated by subtracting the estimated dry weights of seedlings at the beginning of the treatment period from the final dry weights. A water use efficiency value was calculated from the estimated change in whole plant dry weight divided by the estimated water use over the final 2 month treatment period.

The pots that were allowed to dry for the drought regime were weighed every 2-3 weeks after the initial 2-week acclimation period and watered with measured amounts of tap water when needed to maintain 25-30% relative water capacity (RWC), which was found to be at or just above that which caused partial stomatal closure in red, white and bur oak seedlings grown under the same conditions (unpublished data). This range also corresponds to predawn leaf water potentials of the same red, white, and bur oak seedlings, of -1.0 ± 0.3 MPa determined with the use of a pressure bomb (Soilmoisture Plant Water Status Console Model 3005, Santa Barbara, California).

The artificially imposed drought regime lasted for two months. Approximately 1 month was necessary to reach 25-30% RWC and seedlings were maintained for an additional month under mild drought conditions of -1.0 ± 0.3 MPa predawn seedling water potentials. The final seedling heights and calipers were also measured at this time. Then all seedlings were harvested by gently washing the soil mixture from the roots in water and root, shoot, and foliage fresh and oven-dry (70°C for 24 h) weights were determined.

Analysis of variance was used to determine variation due to species, shade and irrigation regimes in a 4x3x2 factorial treatment design with the use of the General Linear Models procedure of SAS (SAS Institute 1982). The experimental design was a systematic split-split plot with shade as main plots and species and irrigation as subunits and sub-subunits respectively. Individual seedlings were randomly assigned to sub-subunits and rerandomized twice during the treatment period. Interactions between these three variables were also included in the model. Scheffe's multiple-comparison procedure was used to determine differences of all main effects (Steel and Torrie 1980).

The number of flushes (foliar growth and expansion between periods of bud set) per tree were also tabulated throughout the study. Specific leaf area was determined at the end of this study by cutting a total of 60 leaf discs 1-cm in diameter (from fully expanded leaves randomly selected from seedlings in each of six shade x drought treatments) for each species and determining the oven-dry weights. The total area of the leaf discs was then divided by the total dry weight to obtain the specific leaf area (cm^2/g).

RESULTS

Irradiance

Growth of oak seedlings of all species combined varied significantly with irradiance levels (Tables 1 and 2). Mean dry weight increment, caliper increment, root and shoot dry weights, and water use efficiency decreased significantly as shade levels increased from 30% to 73%. The shoot/root ratio increased as shade levels increased from 55% to 73%. The caliper increments were similar for the 55% and 73% shade levels and were 20 percent less than those at the 30% shade level. The mean dry weight increment at the 73% shade level was 56 and 42 percent less than at the 30% and 55% shade levels respectively. The water use efficiency declined 42 percent between the 30% and 73% shade levels. Shading had no significant effect on leaf dry weight or height increment.

The effect of irradiance, or shade levels, on white oak followed the same trends as for the regression model with species and irrigation levels pooled, except that shading did not affect the shoot/root ratio (Table 3). The dry weight increment for white oak was 83% less at the 73% shade level compared with the 30% shade level. There were consistent increases at the 55% shade level for shoot, root and stem dry weight. The increases were not statistically significant, however, but may have been due to an intermediate-shade reduction of evapotranspiration.

The effect of irradiance on the growth and water use of swamp white oak differed from the overall pattern for all oak species combined in that only mean dry weight increment, root dry weight and shoot dry weight were affected. The mean dry weight increment declined 52 percent from the 30% to the 73% shade level. The root and shoot dry weights were least, though not significantly so, at the intermediate (55%) shade level (Table 4).

The shoot/root ratio was the only growth variable significantly affected by shading in pin oak and shingle oak seedlings. The shoot/root ratio increased 25 percent from the 55 to 73% shade level for both pin and shingle oak (Tables 5 and 6).

Irrigation

Mean growth values for all oak seedlings combined (Table 1) and individual oak species (Table 7) varied significantly with irrigation regimes. Experimentally-imposed drought reduced the mean dry weight increment, root, leaf and shoot dry weights, caliper increment and water use efficiency, while it increased the shoot/root ratio. There were reductions of 65 percent in mean dry weight increment, 42 percent in water use efficiency and 31 percent in caliper increment for all oak species combined over the course of this study. The combined shoot/root ratio mean increased by 22 percent in the drought stressed oak seedlings compared with those at container capacity. Oak height increment was not significantly affected by drought in this study.

Drought decreased the mean dry weight increment of white oak by 67 percent and the dry root weight 25 percent, while it increased the shoot/root ratio by 17 percent relative to seedlings grown with an adequate water supply (Table 7). Drought had no statistically significant effect on water use efficiency, caliper increment, stem, leaf and shoot dry weight, although the values for these variables decreased due to drought at each shade level (Table 3).

The effect of drought on swamp white oak (Table 7) followed the pattern for all oak species combined with the exception that drought did not significantly affect the stem, leaf, and shoot dry weights. Declines were 66 percent in mean dry weight increment, 43 percent in water use efficiency and 87 percent in caliper increment. The root dry weight declined 37 percent and the shoot/root ratio increased 42 percent relative to well-watered swamp white oak seedlings. Growth and water use values declined with drought, while shoot/root ratio increased with drought for all shade levels and stem dry weight increased with drought at the 73% shade level (Table 4). Under the drought regime, water use efficiency increased with shade, but this interaction was not significant.

For pin oak, drought had no detectable effect on stem, leaf, and shoot dry weights (Table 7). Reductions of 67 percent in mean dry weight increment, 42 percent in water use efficiency, 27 percent in caliper increment and 41 percent in root dry weight occurred relative to well watered pin oak seedlings. The mean shoot/root ratio increased 30 percent overall due to drought.

The effect of drought on shingle oak (Table 7) was to decrease the mean dry weight increment by 57 percent and water use efficiency by 59 percent. The dry root weight declined 30 percent and the shoot/root ratio increased 21 percent with drought. Decreases in all variables except shoot/root ratio were found due to drought at all shade levels (Table 6). Shoot/root ratio increased due to drought at each shade level.

A shade x irrigation interaction occurred for the mean dry weight increment of swamp white oak. The mean dry weight increment decreased with shade at container pot capacity, but increased (non-significant) with shade under the drought regime (Table 8).

There is a possibility that size and shoot/root ratio may be correlated and that treatments influencing seedling size influenced this ratio. However, the slopes and intercepts of linear regressions of final dry weight and shoot/root ratio were different for irrigation compared with shade treatments. This indicates that the treatments influenced shoot/root ratios independently from any total plant dry weight relationship.

Other variables measured were number of flushes and specific leaf area. Pin oak flushed the most with an average of 2.5, followed by shingle oak (1.9), swamp white oak (1.6), and white oak (1.0) (Table 9). The specific leaf area was greatest in bottomland pin oak (176.1 cm^2/g) and swamp white oak (174.8 cm^2/g) and lowest for the upland shingle oak (157.7 cm^2/g) and white oak (158.7 cm^2/g).

DISCUSSION

The results of this study are consistent, for the most part, with the findings of Musselman and Gatherum (1969), who found that stem, leaf, shoot, and root dry weight decreased with shade and with reductions in available soil moisture for northern red oak seedlings. In contrast with the Musselman and Gatherum results, we did not find any significant increase in height of four oak species with increased shade. Increases in shoot/root ratio with decreases in soil moisture were also reported by Gatherum et al. (1963) for species of two hardwood and three coniferous seedlings. Norby and O'Neill (1989) reported a greater water use efficiency for white oak (6.3 mg cm^{-3}) than our overall mean (1.81 mg cm-$^{-3}$). However, this discrepancy may be due to their use of first year seedlings rather than third year seedlings from bare-root nursery stock as employed in this study.

White oak is generally considered intermediate in shade tolerance and is more tolerant than the red oaks (Fowells 1965). Swamp white oak, a member of the white oak group, is also considered intermediate in shade tolerance (Fowells 1965). Pin oak, in the red oak group, is a common associate of swamp white oak. However, pin oak is considered to be intolerant of shade and it is recommended that pin oak receive at least 2/3 of full solar irradiance for successful regeneration

(Fowells 1965). Shingle oak, another member of the red oak group, occurs on a variety of sites, from dry upland ridges to rich and moist river bank soils (Iles 1988). Although there is little published research on the biology of shingle oak, it is considered to be somewhat intolerant of shade (Elias 1980).

In this study (Tables 3 and 4), 55% shade did not markedly reduce growth or water use efficiency of the white oaks relative to 30% shade. However, reduction in irradiance caused by the 73% shading did reduce growth and water use efficiency significantly in comparison with lower shade levels. Hence, increases in solar irradiance above 45% will probably not benefit growth as markedly as decreases in solar irradiance below 45% will inhibit growth. This study revealed few differences among shade levels between 30 and 73% on growth and water use efficiency of shingle and pin oak (Tables 5 and 6) in comparison to the white oaks.

Although shingle oak and pin oak are considered shade intolerant, the only response these species exhibited to the tested shade levels was to increase shoot/root ratio with shade (Tables 5 and 6). This response is indicative of shade intolerant trees such as jack pine (*Pinus banksiana*)(Kimmins 1987) and yellow poplar (*Liriodendron tulipifera*)(Loach 1970). Shade intolerant trees show a greater increase in shoot/root ratio as shade increases than do more tolerant species. Newhouse and Madgewick (1968) have found that rapid shoot growth in tree species is associated with intolerance of shade. Other authors have noted that the more tolerant tree species are characterized by the maintenence of a uniform pattern of growth over a wide range of shade (Baker 1945, Loach 1967 and Loach 1970). Consistent with these patterns, shingle oak and pin oak (Tables 5 and 6) showed an increase in shoot/root ratio with increasing shade while the more tolerant white oak and swamp white oak did not (Tables 3 and 4). Additionally, shade intolerant and faster growing shingle oak and pin oak flushed more times than the more tolerant white oak and swamp white oak seedlings. Reich et al. (1980) stated that multiple flushes occur in white, bur and post oak seedlings during the spring under conditions of favorable light and moisture, while single flushes occur when unfavorable conditions are present. Shingle oak and pin oak seem to be able to flush repeatedly, and more times than the white oaks, even when conditions are only marginally favorable for growth.

White oak and shingle oak seedlings seem to be more drought tolerant than pin oak and swamp white oak seedlings. Four important characteristics that can be used to help indicate drought tolerance in a tree species are higher water use efficiency, lower shoot/root ratio, lower specific leaf area, and less stem diameter inhibition than drought intolerant species (Gottschalk 1985, Larcher 1980). White oak alone exhibited an ability to maintain similar water use efficiency values under either irrigation regime (Table 7). Under the drought regime, rankings for water use efficiency from highest to lowest were: shingle oak (1.73 mg cm^{-3}), white oak (1.65 mg cm^{-3}), pin oak (1.46 mg cm^{-3}) and swamp white oak (1.01 mg cm^{-3}). The rankings for shoot/root ratio under drought from lowest (most advantageous) to highest were: white oak (0.60), shingle oak (0.87), pin oak (0.96), and swamp white oak (1.08). With moisture and shade treatments combined (no significant differences among them in area to weight ratio), the upland white oak and shingle oak had the lowest specific leaf areas. Such low

specific leaf areas are characteristic of drought avoiders (Larcher 1980). Caliper increment (radial stem growth) of oaks is much more sensitive to stress and limiting factors than other variables such as height growth (Gottschalk 1985). The bottomland species, pin oak and swamp white oak, were the only species that showed a significant decrease in caliper increment due to drought. Swamp white oak was the most sensitive of the two as its caliper increment declined 86 percent, while pin oak's declined only 35 percent relative to the radial stem growth increments of well watered seedlings.

Under drought conditions, species that maintain a low shoot/root ratio are able to maximize water uptake by having a greater root surface to exploit scarce soil water and minimize evapotranspiration through reduced foliage quantity. Plants with a high water use efficiency under dry soil conditions can more efficiently use available water in producing phytomass (Larcher 1980). The two upland species, white oak and shingle oak, differed in their physiological responses to drought. Overall, white oak had a lower shoot/root ratio (0.56) than shingle oak (0.80), while shingle oak had a greater water use efficiency than white oak (Table 10). These differences may reflect different adaptive strategies to drought of these two upland oak species. The more shade intolerant shingle oak, with its high water use efficiency and high shoot/root ratio, is better equipped to compete both on droughty soils and on fertile sites where both soil moisture and irradiance may be limited due to competition from fast growing plants.

The two white oak species in this experiment exhibited higher shade tolerance and lower water use efficiencies than the two red oak species studied.

Pin oak and shingle oak are species which inhabit sites that may experience flooding and drought during the same growing season. Thus high water use efficiencies may be a physiological adaptation allowing pin and shingle oaks to grow on sites with alternating wet and dry periods. High water use efficiencies and high shoot/root ratios together allow a tree to compete well for solar radiation while at the same time efficiently using limited soil water resources on good sites where vegetative competition is great. Our results indicate that shingle oak is better able to maintain a high water use efficiency under drought conditions in comparison with pin oak. Furthermore, shingle oak does not drastically increase its shoot/root ratio in response to drought as does pin oak. This may be due in part to the coarse root system of shingle oak which is more sensitive to stress than the highly fibrous root system of pin oak (Struve and Moser 1984). Shingle oak is found more on dry upland sites than is pin oak, perhaps owing to the noted differences in functional and structural response to drought between these two species.

Of the white oaks, swamp white oak seems to be the most site specific. It had the lowest water use efficiency and highest shoot/root ratio for any of the oak species in this study (Table 10). This is consistent with its natural occurrence on poorly drained-upland depressions, swamp margins, stream banks and moist, peaty flats (Fowells 1965), sites which rarely undergo drought. Swamp white oak exhibited an irradiance x drought interaction (Table 8) in that at container water capacity the dry weight increment decreased with shade, but increased with shade under drought conditions. This interaction is probably due to a reduction

in evapotranspiration of this midtolerant oak species caused by shade under drought conditions.

The extension of these data to ecological behavior of these oak species requires caution. In a forest not only is the quantity of light changed, but also the quality of light as the overstory canopy differentially absorbs and transmits various wavelengths of PAR and other solar radiation. Also, frequent dieback or browsing of advance oak regeneration will influence shoot/root ratios in the field. Hence the results of this study relate more to early establishment and growth of oak seedlings in forest understories than to the longer-term patterns of growth and development of advance oak regeneration, and should be extrapolated to field conditions with caution until confirmed by field studies.

SUMMARY

This study has shown that both increasing shade and drought decrease the growth and water use efficiency of four oak species of the central United States. Overall, the red oaks (shingle and pin oak) had the highest water use efficiencies and flushed more than white oak and swamp white oak, consistent with the generally faster juvenile growth rates of intolerant species. Shingle and pin oak also increased markedly in shoot/root ratio in response to shade, which is a characteristic of shade intolerant trees. Swamp white oak and white oak have the characteristics of midtolerant species, maintaining similar shoot/root ratios under a range of intermediate shade levels, exhibiting fewer flushes and smaller caliper increments overall in comparison with the two red oaks.

Under drought conditions, white oak and shingle oak had the lowest shoot/root ratios, highest water use efficiencies and smallest specific leaf areas, appropriate to their observed ability to grow on dry sites. However, both white and shingle oaks seem to have broad ecological amplitudes with respect to soil water availability, growing on mesic sites and, in the case of shingle oak, also on moist soils and on poorly drained flats with pin oak and post oak. Pin oak, which was between white oak and swamp white oak in shoot/root ratio and water use efficiency values under drought conditions, and similar to swamp white oak in specific leaf area, occurs in bottomland areas subject to flooding and in pin oak -post oak flats with a fragipan creating alternating wet and dry conditions. Swamp white oak and pin oak, the bottomland species, were the only ones to exhibit a significant decrease in caliper increment with drought. Swamp white oak was the most sensitive of the four oak species to drought, consistent with its ecologically narrow niche of moist sites.

This study examined two of the most important factors influencing forest regeneration, irradiance and soil moisture. The results indicate that the two white oaks were more shade tolerant than the two red oaks and will, therefore, more successfully survive in smaller openings and under denser canopies than pin and shingle oak. The data show a tendency suggesting that on sites where soil moisture may be limiting part of the season, shade levels from 55-73% may reduce evapotranspiration and increase growth of swamp white oak seedlings compared with more open conditions on the same site. Shingle oak may be a suitable native tree for minespoil reclamation and urban planting due to its drought tolerance and high water use efficiency described in this study

combined with its moderately fast growth rate, mast production for wildlife and tolerance of wide pH ranges (Iles 1968).

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Table 1. Analysis of variance for growth and water use variables of four oak species grown under wet and dry irrigation regimes and three shade levels.

Source of variation	Degrees of freedom	Mean squares for					
		Dry Wt. Increment	Water Use Efficiency	Root Dry Wt.	Stem Dry Wt.	Leaf Dry Wt.	Top Dry Wt.
Oak Species	3	87.76*	27.90**	6144.32**	583.94**	108.56**	1176.32**
Shade Regime	2	288.67**	25.25**	358.49**	30.40**	15.57	70.52*
Spec. x Shade.	6	70.95*	7.12	214.96**	24.60*	10.79	62.90**
Irrigation Regime	1	1331.51**	78.48**	1131.52**	9.78	43.29**	94.21*
Spec. x Irr.	3	26.61	14.43**	75.55	0.64	1.50	3.20
Shade x Irr.	2	149.76**	4.52	45.40	5.20	4.81	18.53
Spec. x Shd. x Irr.	6	21.73	0.90	24.27	2.73	2.63	9.87
Error	256	29.77	3.68	44.65	4.46	5.51	16.66

Source of variation	Mean squares for		
	Shoot/Root Ratio	Caliper Increment (x1000)	Height Increment
Oak Species	1.91**	18.54**	79.01
Shade Regime	0.23*	1.73**	60.89
Spec. x Shade.	0.17*	1.36**	79.65
Irrigation Regime	2.66**	7.81**	16.78
Spec. x Irr.	0.20*	1.10	77.60
Shade x Irr.	0.05	0.19	89.49
Spec. x Shd. x Irr.	0.06	0.28	54.47
Error	0.06	0.32	55.61

* Significant at the 0.05 level
** Significant at the 0.01 level

Table 2. Mean growth and water use values for oak seedlings grown at three shade levels, with four oak species and two soil moisture levels pooled.

GROWTH VARIABLE	PERCENT SHADE		
	30	55	77
Observations (n=)	95	92	93
Dry Weight Increment (g)	6.23 a*	4.66 a	2.72 b
Water Use Efficiency ($mg\ cm^{-3}$)	2.45 a	2.11 a	1.42 b
Root Dry Weight (g)	12.80 a	13.30 a	9.42 b
Stem Dry Weight (g)	3.79 a	4.02 a	2.86 b
Leaf Dry Weight (g)	4.47 ns	3.91	3.64
Shoot Dry Weight (g)	8.26 a	7.94 ab	6.51 b
Shoot/Root Ratio (dry weight)	0.75 ab	0.72 b	0.82 a
Caliper Increment (mm)	0.34 a	0.27 b	0.26 b
Height Increment (cm)	15.02 ns	13.72	13.57

* Means within a row followed by the same letter are not significantly different at 0.05 level according to Scheffe's test.

Table 3. The effects of shade on growth and water use variable means of white oak.

WHITE OAK

Percent Shade	Irrigation Level	N	Water Use Efficiency	Root Dry Weight (g)	Stem Dry Weight (g)	Leaf Dry Weight (g)	Shoot Dry Weight (g)
30	CC#	15	2.78	28.91	7.89	7.12	15.02
	DR	15	2.27	20.61	6.82	5.41	12.23
	Mean+	30	2.53a*	24.76a	7.36a	6.27ns	13.62a
55	CC	14	2.51	33.92	9.74	6.99	16.74
	DR	15	2.34	24.64	8.41	5.31	13.72
	Mean	29	2.42a*	29.28a	9.08a	6.15	15.23a
73	CC	13	0.60	18.82	4.83	4.34	9.17
	DR	15	0.34	16.64	5.71	4.32	10.03
	Mean	28	0.47b	17.73b	5.27b	4.33	9.60b

Percent Shade	Irrigation Level	N	Dry Wt. Increment (g)	Shoot/Root Ratio	Caliper Increment (mm)	Height Increment (cm)
30	CC	15	13.43	0.52	0.38	13.73
	DR	15	4.17	0.63	0.038	15.20
	Mean	30	8.80a	0.57ns	0.38a	14.47ns
55	CC	14	10.64	0.50	0.24	13.79
	DR	15	4.09	0.57	0.17	13.63
	Mean	29	7.36a	0.54	0.20 b	13.71
73	CC	13	2.32	0.53	0.15	10.74
	DR	15	0.75	0.60	0.09	10.20
	Mean	28	1.53 b	0.57	0.12 b	10.47

\# CC is the 90-95% container capacity regime, DR is the drought regime (20-25% container capacity).
\+ Mean is for the pooled irrigation values at the given shade level.
* Means within a column followed by the same letter were not significantly different at 0.05 level according to Scheffe's test.
ns Not significant.

Table 4. The effects of shade on growth and water use variable means of swamp white oak.

SWAMP WHITE OAK

Shade Level	Irrigation Level	N	Water Use Efficiency	Root Dry Weight (g)	Stem Dry Weight (g)	Leaf Dry Weight (g)	Shoot Dry Weight (g)
30	CC#	12	2.55	9.23	2.61	4.54	7.15
	DR	13	0.98	5.42	2.28	3.12	5.40
	Mean+	25	1.76ns	7.33a*	2.44ns	3.83ns	6.28ns
55	CC	11	1.43	6.55	2.12	2.77	4.89
	DR	12	0.93	4.07	1.81	2.78	4.59
	Mean	23	1.18	5.31 b	1.97	2.78	4.74
73	CC	14	1.44	7.06	2.06	3.21	5.27
	DR	11	1.14	4.86	2.76	2.76	4.94
	Mean	25	1.29	5.96ab	2.12	2.98	5.10

Shade Level	Irrigation Level	N	Dry Wt. Increment (g)	Shoot/Root Ratio	Caliper Increment (mm)	Height Increment (cm)
30	CC	12	8.81	0.79	0.27	19.29
	DR	13	1.63	1.01	0.03	16.65
	Mean	25	5.22a	0.90ns	0.15ns	17.97ns
55	CC	11	3.89	0.75	0.14	9.86
	DR	12	1.70	1.16	0.05	17.12
	Mean	23	2.79ab	0.96	0.10	13.49
73	CC	14	3.05	0.75	0.24	13.78
	DR	11	1.93	1.08	0.01	14.95
	Mean	25	2.49 b	0.91	0.12	14.37

CC is the 90-95% container capacity regime, DR is the drought regime (20-25% container capacity).
\+ Mean is for the pooled irrigation values at the given shade level.
* Means within a column followed by the same letter were not significantly different at 0.05 level according to Scheffe's test.
ns Not significant.

Table 5. The effects of shade on growth and water use variable means of pin oak.

PIN OAK

Percent Shade	Irrigation Level	N	Water Use Efficiency	Root Dry Weight (g)	Stem Dry Weight (g)	Leaf Dry Weight (g)	Shoot Dry Weight (g)
30	CC#	10	2.88	9.67	2.99	3.52	6.52
	DR	10	1.57	5.05	1.76	2.42	4.18
	Mean+	20	2.22ns	7.36ns	2.38ns	2.98ns	5.35ns
55	CC	10	2.47	8.12	2.07	3.28	5.36
	DR	10	1.14	5.02	1.67	2.62	4.29
	Mean	20	1.81	6.57	1.87	2.95	4.82
73	CC	10	2.14	6.66	1.84	3.28	5.12
	DR	10	1.67	4.35	1.88	3.36	5.24
	Mean	20	1.91	5.50	1.86	3.32	5.18

Percent Shade	Irrigation Level	N	Dry Wt. Increment (g)	Shoot/Root Ratio	Caliper Increment (mm)	Height Increment (cm)
30	CC	10	8.42	0.68	0.56	15.85
	DR	10	2.11	0.82	0.51	10.25
	Mean	20	5.26ns	0.75 b*	0.54ns	13.05ns
55	CC	10	6.23	0.66	0.60	14.60
	DR	10	1.70	0.82	0.36	13.05
	Mean	20	3.96	0.74 b	0.42	13.82
73	CC	10	4.40	0.77	0.63	14.40
	DR	10	2.55	1.22	0.44	16.30
	Mean	20	3.48	1.00a	0.54	15.35

CC is the 90-95% container capacity regime, DR is the drought regime (20-25% container capacity).
\+ Mean is for the pooled irrigation values at the given shade level.
* Means within a column followed by the same letter were not significantly different at 0.05 level according to Scheffe's test.
ns Not significant.

Table 6. The effects of shade on growth and water use variable means of shingle oak.

SHINGLE OAK

Shade Level	Irrigation Level	N	Water Use Efficiency	Root Dry Weight (g)	Stem Dry Weight (g)	Leaf Dry Weight (g)	Shoot Dry Weight (g)
30	CC#	10	5.08	8.33	1.53	4.39	5.92
	DR	10	1.79	6.14	1.54	3.82	5.35
	Mean+	20	3.44ns	7.24ns	1.54ns	4.10ns	5.63ns
55	CC	10	3.91	7.22	1.31	3.09	4.40
	DR	10	2.09	5.44	1.21	2.86	4.07
	Mean	20	3.00	6.33	1.26	2.98	4.24
73	CC	10	3.61	7.42	1.70	4.38	6.08
	DR	10	1.29	4.48	1.10	3.23	4.33
	Mean	20	2.45	5.98	1.40	3.80	5.20

Shade Level	Irrigation Level	N	Dry Wt. Increment (g)	Shoot/Root Ratio	Caliper Increment (mm)	Height Increment (cm)
30	CC	10	7.17	0.74	0.33	17.05
	DR	10	2.70	0.89	0.32	11.35
	Mean	20	4.94ns	0.81ab*	0.33ns	14.20ns
55	CC	10	4.26	0.62	0.40	14.40
	DR	10	3.00	0.74	0.34	13.00
	Mean	20	3.63	0.68 b	0.37	13.70
73	CC	10	6.03	0.81	0.38	16.35
	DR	10	1.86	0.99	0.34	14.15
	Mean	20	3.93	0.90a	0.36	15.25

CC is the 90-95% container capacity regime, DR is the drought regime (20-25% container capacity).
\+ Mean is for the pooled irrigation values at the given shade level.
* Means within a column followed by the same letter were not significantly different at 0.05 level according to Scheffe's test.
ns Not significant.

Table 7. The effects of drought on the growth and water use of white (WO), swamp white oak (SWO), pin oak (PO) and shingle oak (SO).

Species	Irrigation Level	N	Water Use Efficiency	Root Dry Weight (g)	Stem Dry Weight (g)	Leaf Dry Weight (g)	Shoot Dry Weight (g)
WO	CC#	42	1.96ns	27.45*	7.56ns	6.22ns	13.78ns
	DR	45	1.65	20.63	6.98	5.01	11.99
SWO	CC	37	1.79*	7.61*	2.26ns	3.51ns	5.77ns
	DR	36	1.01	4.80	2.09	2.90	4.99
PO	CC	30	2.50*	8.15*	2.30ns	3.36ns	5.66ns
	DR	30	1.46	4.81	1.77	2.80	4.57
SO	CC	30	4.20*	7.68*	1.51ns	3.95ns	5.46ns
	DR	30	1.73	5.35	1.28	3.30	4.58
MEAN	CC	139	2.53*	13.74*	3.71ns	4.39*	8.10*
	DR	141	1.46	9.97	3.41	3.64	7.05

\# CC is the 90-95% container capacity regime, DR is the drought regime (20-25% container capacity).
* Means within the column pair for an oak species are significantly different at 0.05 level according to the F-test.
ns Not significant.

Table 7 (Cont'd). The effects of drought on the growth and water use of white (WO), swamp white oak (SWO), pin oak (PO) and shingle oak (SO).

Species	Irrigation Level	N	Dry Wt. Increment (g)	Shoot Root Ratio	Caliper Increment (mm)	Height Increment
WO	CC#	42	9.06*	0.52*	0.30ns	12.82ns
	DR	45	3.00	0.60	0.21	13.01
SWO	CC	37	5.17*	0.76*	0.22*	14.40ns
	DR	36	1.74	1.08	0.03	16.29
PO	CC	30	6.35*	0.70*	0.59*	14.95ns
	DR	30	2.12	0.96	0.44	13.20
SO	CC	30	5.82*	0.72*	0.37ns	15.93ns
	DR	30	2.52	0.87	0.33	12.83
MEAN	CC	139	6.74*	0.67*	0.35*	14.37ns
	DR	141	2.39	0.87	0.24	13.85

CC is the 90-95% container capacity regime, DR is the drought regime (20-25% container capacity).
* Means within the column pair for an oak species are significantly different at 0.05 level according to the F-test.
ns Not significant.

Table 8. Interaction of shade and drought on the dry weight increment (g) of swamp white oak.

	Shade Percentage			
Irrigation	30	55	73	Mean
Container Capacity	8.81 n=12	3.89 n=11	3.05 n=14	5.17**
Drought Regime	1.63 n=13	1.70 n=12	1.93 n=11	1.74
Mean	5.22 a	2.79 ab	2.49 b*	

* Means within a row followed by the same letter were not significantly different at 0.05 level according to Scheffe's test.
** Means in the column are significantly different at 0.05 level according to the F test.

Table 9. The effect of irrigation regime on the observed number of flushes of four oak species.

	Observed Flushes			
Species	Container Capacity	Drought Regime	Mean	Range
White oak	1.00	1.01	1.00	1-2
Swamp white oak	1.68	1.61	1.64	1-3
Pin oak	2.70	2.30	2.50	1-4
Shingle oak	2.00	1.77	1.90	1-3

Table 10. Sources of variation among species, with shade and irrigation levels pooled.

Species	Water Use Efficiency ($mg\ cm^{-3}$)	Shoot/Root Ratio	Caliper Increment (mm)
White oak	1.81 b*	0.56 c	0.24 c
Swamp white oak	1.41 b	0.92a	0.12 d
Pin oak	1.98ab	0.83ab	0.52a
Shingle oak	2.96a	0.80 b	0.35 b

* Means within a column followed by the same letter were not significantly different at 0.05 level according to Scheffe's test.

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A Study of Four River Birch Stands in Mason and Cass Counties, Illinois

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ABSTRACT

Four stands of *Betula nigra* L. (river birch) were surveyed in Mason and Cass Counties, Illinois. River birch was the dominant overstory species in each of the study areas, accounting for 83% to 92% of the basal area and 75% to 87% of the overstory individuals. Other species encountered included black oak, black cherry, black hickory, silver maple, American elm, sassafras and green ash. All sites studied were in shallow depressions underlain by acidic, sandy soils.

INTRODUCTION

Betula nigra (river birch) is a common woody species in eastern United States, occurring from southeastern New York, south to northwest Florida, and west to northeast Texas, Oklahoma, Missouri, Iowa, and Wisconsin (Little, 1971). Cribben and Ungar (1974) report that river birch forests are frequent along smaller streams and in poorly drained areas as far north as southeastern Ohio. They also found that its distribution is closely related to acid mine drainage into streams in these unglaciated areas. Braun (1943) states that river birch occur on more acid soils of Kentucky.

In Illinois, river birch occurs commonly in the southern, central and western parts of the state with very few collections from within the area of Wisconsin glaciation (Mohlenbrock and Ladd, 1978). In southern Illinois, Voight and Mohlenbrock (1964) reported that river birch occurs on poorly drained soils which are low in organic matter. Fritts and Kirkland (1960) found that river birch is

common along streams in Cumberland County, Illinois, which drain the more acid soils of the Illinoian age glacial deposits. They also reported that it is absent along streams which drain the more alkaline materials from the Wisconsin moraine to the north. Nearly pure stands of river birch are occasionally found in depressions in the Illinois River Section of the Illinois River and Mississippi River Sand Area Division (Schwegman, 1973). A study of these forests was undertaken to determine their floristic composition and to examine the soil conditions under which they presently exist.

METHODS

During the fall of 1988, four river birch stands were surveyed in Mason and Cass Counties, Illinois. Studied stands were divided into quadrats 25 m on a side (0.0625 ha) and the number, size, and species of all living and dead -standing trees above 10 cm dbh were recorded for each quadrat. At each site, the maximum number of quadrats were placed to completely survey the entire forest, leaving at least a 10 m buffer strip around the perimeter to eliminate edge effects. Relative density, relative dominance, and importance value (IV) were then calculated for each species in each of the areas sampled. The IV determination follows the procedure developed by McIntosh (1957), and later by Boggess (1964), and is the sum of the relative density and relative dominance. Also determined for each species was the density (stems/ha) and the basal area (sq m/ha) for each stand.

In each of the 25 x 25 m quadrats, nested circular plots, .0001 and .01 ha in size, were randomly located using a blind throw of a marker from the southwest corner of each quadrat. In the smaller plot, seedlings (less than 2.5 cm dbh) were recorded, while in the larger plot, saplings (2.5-10.0 cm dbh) were recorded and their densities (stems/ha) determined. Nomenclature follows Mohlenbrock (1975).

At each site, two soil pits were dug to determine the depth and soil texture of the A and B horizons, and the presence of a hardpan. Also, soil samples were then taken from the A and B horizons in odd-numbered 25 x 25 m quadrats for determination of pH. Soil samples were analyzed for pH using a Corning model 7 pH meter, while soil texture was determined (three replicates) using the Bouyoucos Hydrometer Method (Bouyoucos, 1962).

Listed below are the four river birch stands studied along with their general site and soil characteristics.

Kilbourne Site 1: This stand, which is about 1/8 ha in size, occurs in the southwest part of Mason County, Illinois, (NE1/4 Sec 35 T20N R9W) three miles west of the town of Kilbourne. This plant community is in a small depression between stabilized sand dunes on which the dominant vegetation is *Quercus velutina* (black oak). It occurs on Dune Sand (Smith et al., 1924) which was deposited during the melting of the Wisconsin glaciers and later re-worked by wind. This terrace soil type is low in organic material, and may have a plastic, impervious, mottled yellow clay hardpan.

Kilbourne Site 2: This stand is about 1/4 ha in size, and is located 200 m north of Site 1 (NE1/4 Sec 35 T20N R9W). It is located in a small depression between stabilized sand dunes on which the dominant vegetation is black oak. The soil is similar to that of Kilbourne site 1.

Matanzas Prairie Site: This stand is about 1 ha in size, and is located in the Matanzas Prairie Nature Preserve (N1/2 Sec 4 T20N R9W) 1 1/2 miles northeast of Bath, Mason County, Illinois. It is located in a drainage depression about 1/2 m lower than the wet prairie, occurring on Brown-Gray sandy loam on tight clay (Smith et al., 1924). This terrace soil is relatively low in organic material, and has a plastic, impervious, mottled yellow clay subsoil.

Bluff Springs Site: This stand, which is about 1 1/2 ha in size, is located in the west-central part of Cass County, Illinois, (NE1/4 Sec 34 T18N R11W) about two miles southeast of Bluff Springs. It is in a low area with the topography rising 2-4 m on the west and north side, and is bounded on the east and south by county roads. It occurs on Orio sandy loam (Smith et. al., 1947) which developed under grass vegetation on an old sandy river deposit. This terrace soil is relatively low in organic material, while the subsoil is a gray sandy clay heavily mottled with yellow and only slowly permeable to water.

RESULTS

At Kilbourne site 1, the number of overstory stems/ha is 504 while the basal area averages 18.9 sq m/ha (Table 1). The dominant overstory species is river birch with an IV of 176.7 (out of a possible 200), followed by black oak (IV of 18.5) and small numbers of *Carya tomentosa* (mockernut hickory), and *Ulmus americana* (American elm). The only dead-standing trees in the woodlot are river birch (16 stems/ha with an average diameter of 16.7 cm). A few black oak, *Carya texana* (black hickory), and river birch seedlings are present in the understory, while *Prunus serotina* (black cherry) and American elm saplings are also occasionally encountered. None, however are common, and the understory is open. The soil in this woodlot is extremely sandy and acidic. The A horizon has a pH of 5.3 and is 90% sand, while the B horizon has a pH of 5.7 and is 96% sand (Table 2).

At Kilbourne site 2, the number of overstory stems/ha is 448 while the basal area averages 19.67 sq m/ha (Table 1). River birch is the dominant overstory species with an IV of 168.4, followed by black oak (IV of 28.8), and a few *Quercus marilandica* (blackjack oak). Black oak, although not as abundant as river birch, shows a similar size class distribution. Dead-standing individuals include river birch (72 stems/ha with an average diameter of 12.5 cm) and black oak (40 stems/ha with an average diameter of 13.7 cm). No river birch seedlings or saplings were recorded at this site. In contrast, black oak, black hickory, and black cherry, were well represented in the seedling layer, with black and blackjack oaks the only species present in the sapling layer. The soil in this woodlot is extremely sandy and acidic. The A horizon has a pH of 5.3 and is 86% sand, while the B horizon has a pH of 4.8 and is 88% sand (Table 2).

At the Matanzas Prairie site, the number of overstory stems/ha is 579 while the basal area averages 24.04 sq m/ha (Table 2). The dominant overstory species is river birch (IV of 179.2), followed by green ash (IV of 10.8), *Acer saccharinum* (silver maple), American elm, *Sassafras albidum* (sassafras), *Diospyros virginiana* (persimmon), and *Platanus occidentalis* (sycamore). The only species with dead-standing individuals was river birch with 80 stems/ha and having an average diameter of 35.9 cm. At this site the understory is more diverse, and more than twice as dense as that found at the other three sites examined (15798 stems/ha). As is typical of the other sites, however, river birch is only of minor importance in the understory. American elm, F*raxinus pennsylvanica* (green ash), sassafras, and the shrub *Rhamnus frangula* (glossy buckthorn) are common components of the seedlings layer along with smaller numbers of black cherry, *Quercus alba* (white oak), and *Morus rubra* (red mulberry). The sapling layer is dominated by American elm, green ash and glossy buckthorn, along with occasional individuals of river birch, sassafras, black cherry, and red mulberry. The soil in this woodlot is very sandy and either acidic or alkaline depending on the horizon (Table 2). The A horizon has a pH of 5.95 and is 68% sand, while the B horizon has a pH of 7.35 and is 78% sand.

At the Bluff Springs site, the number of overstory stems/ha is 616 while the basal area averages 20.77 sq m/ha (Table 1). River birch is the dominant tree (IV of 160.4), with silver maple second (IV of 36.7) and American elm (IV of 2.9) third. The only dead-standing trees in this woodlot are river birch (63 stems/ha with an average diameter 21.0 cm). Both silver maple and American elm are common components of the 10-20 cm diameter class, with only a few larger individuals encountered. No river birch seedlings or saplings were recorded at this site. In contrast, silver maple, American elm, sassafras, and black cherry are represented in the seedling layer, while silver maple and American elm dominate the sapling layer. The soil in this woodlot is sandy and acidic. The A horizon has a pH of 5.3 and is 68% sand, while the B horizon has a pH of 5.7 and is 72% sand (Table 2).

DISCUSSION

At all four sites, river birch dominates the sandy depressions in which the soil is fairly acidic (A horizon pH of 5.30-5.95). According to Cribben and Ungar (1974), these wet, acidic and sandy conditions are ideal for river birch to reach maturity. On the sites examined, river birch accounts for 83% to 92% of the basal area and 75% to 87% of the overstory individuals. It is abundant in the lower diameter classes on each site, which suggests that it will continue to be the dominant overstory species for the immediate future.

Although river birch is by far the dominant species on the sites studied, the subordinate and understory species are highly variable. Both Kilbourne sites support some xerophytic species (black oak, blackjack oak, black hickory), while the Matanzas Prairie and Bluff Springs sites support many mesophytic species. At the Kilbourne sites black hickory and black oak dominate the seedling strata while black oak ranks second in importance in the overstories. The high percentage of sand in the soil on these two sites (exceeding 86% in the A horizon) indicates a poorly developed, relatively thin A horizon (Table 2) which is

very low in organic material (Smith et al., 1924). In contrast, at the Matanzas Prairie and the Bluff Springs sites, most of the subordinate overstory and understory species are usually associated with mesophytic and hydrophytic conditions. At these two sites the A horizon is thicker, less sandy (Table 2), and higher in organic material (Smith et al., 1924, 1947).

At two of the sites (Kilbourne site 2 and Bluff Springs site) no river birch seedlings or saplings were recorded while at the other sites only a small number were encountered. At all of the sites, river birch saplings are not advancing into the lower diameter classes. At both Kilbourne sites, other species, such as the black oak, blackjack oak and black hickory, that are slightly more shade tolerant, could possibly increase in importance to the detriment of the extremely shade intolerant river birch. At the Bluff Springs site, even though the river birch is the dominant overstory species, American elm and silver maple appear to be the dominant understory species and will probably become more important in the future. At the Matanzas Prairie site, green ash will probably increase in importance since it is well represented in the seedling, sapling, and lower diameter classes. There is a drastic change in the soil pH at this site, ranging from 5.95 in the A horizon to 7.35 in the B horizon. Cribben and Ungar (1974) suggests that when the pH of the soil rises to neutral and beyond, river birch densities tend to decline.

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Table 1. Densities, basal areas, importance values and average diameters of the woody species in river birch stands located in Mason and Cass Counties, Illinois

Species	Seed-lings #/ha	Sap-lings #/ha	Density #/ha	Basal Area m^2/ha	I.V.	Av. Diam. (cm)
Kilbourne Site 1: (NE1/4 Sec 35 T20N R9W, Mason Co., IL)						
Betula nigra L.	500	--	440	16.88	176.7	21.5
Quercus velutina Lam.	2500	--	48	1.70	18.5	19.4
Carya tomentosa (Poir.) Nutt.	--	--	8	0.19	2.6	17.5
Ulmus americana L.	--	50	8	0.10	2.2	12.2
Carya texana Buckl.	1500	--	--	--	--	--
Prunus serotina Ehrh.	--	150	--	--	--	--
Totals	4500	200	504	18.87	200.0	--
Kilbourne Site 2: (NE1/4 Sec 35 T20N R9W, Mason Co., IL)						
Betula nigra L.	--	--	384	16.27	168.4	21.8
Quercus velutina Lam.	1750	75	56	3.21	28.8	24.4
Quercus marilandica Muenchh.	250	100	8	0.19	2.8	17.2
Carya texana Buckl.	1750	--	--	--	--	--
Prunus serotina Ehrh.	1500	--	--	--	--	--
Juglans nigra L.	250	--	--	--	--	--
Totals	5500	175	448	19.67	200.0	--
Matanzas Prairie Site: (N1/2 Sec 4 T20N R9W, Mason Co., IL)						
Betula nigra L.	--	50	504	22.13	179.2	22.6
Fraxinus pennsylvanica Marsh.	2833	133	37	1.05	10.8	18.3
Acer saccharinum L.	--	--	8	0.36	2.9	22.9
Ulmus americana L.	8000	1750	13	0.13	2.8	11.3
Sassafras albidum (Nutt.) Nees.	833	33	11	0.22	2.7	15.7
Diospyros virginiana L.	--	--	3	0.08	0.8	19.5
Platanus occidentalis L.	--	--	3	0.07	0.8	18.1
Prunus serotina Ehrh.	333	83	--	--	--	--
Quercus alba L.	167	--	--	--	--	--
Rhamnus frangula L.	1166	200	--	--	--	--
Morus rubra L.	167	50	--	--	--	--
Totals	13499	2299	579	24.04	200.0	--
Bluff Springs Site: (NE1/4 Sec 34 T18N R11W, Cass Co., IL)						
Betula nigra L.	--	--	461	17.77	160.4	20.7
Acer saccharinum L.	750	869	143	2.81	36.7	14.5
Ulmus americana L.	1438	219	12	0.19	2.9	13.0
Sassafras albidum (Nutt.) Nees.	188	--	--	--	--	--
Prunus serotina Ehrh.	63	--	--	--	--	--
Totals	2439	1088	616	20.77	200.0	--

Table 2. Soil texture, depth and pH of A horizon, B horizon, and depth of the hardpan for the soils in each of the river birch forests surveyed in Mason and Cass Counties, Illinois.

	A HORIZON		B HORIZON		HARDPAN
	Depth (cm)	pH	Soil Texture	pH	Soil Texture	Depth from surface (cm)
Kilbourne Site 1:						
	13.0	5.30	90% Sand 7% Silt 3% Clay	5.70	96% Sand 4% Silt 0% Clay	absent
Kilbourne Site 2:						
	20.0	5.30	86% Sand 10% Silt 4% Clay	5.80	88% Sand 8% Silt 4% Clay	60.0
Matanzas Prairie Site:						
	36.0	5.95	68% Sand 22% Silt 10% Clay	7.35	78% Sand 18% Silt 4% Clay	56.0
Bluff Spring Site:						
	24.0	5.30	68% Sand 19% Silt 13% Clay	5.70	72% Sand 19% Silt 9% Clay	absent

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Lactate Dehydrogenase Activity in Oviducts from Transgenic Mice

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ABSTRACT

Lactate dehydrogenase (LDH) activity in mouse oviducal homogenates was compared between litter mates expressing either human growth hormone (hGH) or human beta Interferon genes. Within a group of litter mates, the presence of the exogenous human gene had no apparent effect on LDH activity. The results are surprising since the transgenics receiving the hGH gene are substantially larger than their litter mates.

INTRODUCTION

The use of transgenic animals in basic research is rapidly expanding due to our increased understanding of the molecular biology of genetic material transfer. However there are currently few reports exploring the potential enzymic changes in the reproductive tract of animals receiving genes especially those which might not normally be evaluated in the reproductive tract. It is conceivable that transgenics may exhibit effects on regulation, directly or indirectly, of genes which are essential in reproduction in either the male or female animal. It has been reported that expression of growth hormone genes in mice is associated with reproductive disorders (Bartke et al., 1988). To further probe this question we have studied the effects of two different transgenic models on a specific enzyme, lactate dehydrogenase (LDH: EC 1.1.1.27), in the female oviduct. From other studies (Farley et al., 1990) it was suggested that LDH is an important

enzyme in the oviduct of mice. Early embryos use both pyruvate and lactate, in preference to glucose, for metabolic energy (Georgiev et al., 1970). LDH catalyzes the interconversion of pyruvate and lactate and, therefore, may have an important role in the regulation of the ratio of these energy sources available for the embryo.

Regulation of the amounts and activities of LDH is certainly of interest in successful embryo development and oviducal transport. In our studies, therefore, transgenic mice were tested in order to determine if the new gene affected LDH activity. Two transgenic models were used: human growth hormone (hGH) and human beta interferon (Interferon).

MATERIALS AND METHODS

Materials

Pyruvate, nicotinamide adenine dinucleotide reduced form (Grade III) (NADH), and Bovine Albumin Serum (BSA, Fraction V) were purchased from Sigma Chemical Co. (St. Louis, MO). All water for reagents was doubly distilled and subjected to a Millipore filter system (Corning mega-pure three liter automatic). Kreb's Ringer bicarbonate buffer was made from 6.9 g/L NaCl, 0.35 g/L KCl, 0.16 g/L KH_2PO_4, 0.14 g/L $MgSO_4$, 0.90 g/L glucose, 2.1 g/L $NaHCO_3$, and 0.18 g/L $CaCl_2$ (pH 7.4). All other chemicals were obtained from standard suppliers.

Mice

Transgenic and nontransgenic litter mates (control mice) were obtained from the colonies of Dr. Thomas E. Wagner, Ohio University, Athens, Ohio and housed in the animal facilities at Illinois State University until used. Transgenic mice used in this study were produced by the methods of Wagner et al., (1981). Transgenic strains used were metallothionine promoter driven transgenic human growth hormone(hGH) and Beta Interferon. All tissues were obtained from transgenic mice (+ Interferon or + hGH) or non-transgenic litter mates (-Interferon or - hGH) of approximately 8 months of age. The animals were sacrificed by cervical dislocation, followed by rapid removal of the oviducts. The oviducts were trimmed of fat, weighed, and kept on ice. They were then placed in 1 mL of Kreb's Ringer bicarbonate buffer in a microcentrifuge tube (1.5 mL polypropylene tube, Tekmar Co., Cincinnati, Ohio) and homogenized using a Brinkmann Polytron (probe size PTA 7K) on a setting of 3 for 30 seconds. All steps were done as rapidly as possible on ice.

Measurement Of Oviducal Activity

All oviducts were analyzed spectrophotometrically at 340 nm using the method of Reeves and Fimognari (1963) . In brief this involved: 1.8 mL of Kreb's Ringer bicarbonate buffer, 0.1 mL of 3.3 mg/mL of NADH, 0.1 mL of 3.9 mg/mL of pyruvate, and 0.2 mL of oviducal homogenate placed in a quartz cuvet and inserted into a Beckman DU-40 spectrophotometer set at 340 nm. A change in

absorbance was monitored for 2 minutes. As a control, a rate was determined for each oviduct using identical conditions but omitting the pyruvate. In all cases, this rate was negligible.

Protein Assay

Protein from oviducal homogenates was evaluated by the method of Lowry et al., (1951) using BSA as a standard.

Specific Activity Calculations

The units of LDH which catalysed the oxidation of umoles of NADH per minute were determined by dividing the rate (change in absorbance at 340 nm per minute) by the extinction coefficient which is 6.2. The specific activity of LDH was calculated by dividing the umoles of NADH oxidized per min per mg of homogenate protein. Statistics were performed using analysis of variance. Data were considered to be significantly different at $p < 0.05$.

RESULTS

The reproductive tracts, specifically the ovaries, of the transgenic mice were observed to be grossly different from those of the controls in the same group as well as different from those of the ICR strain we currently work with in the laboratory. Location of the ovaries proved especially difficult from the hGH transgenics because the tissues were embedded in a large layer of fat. In addition, we noted that the ovaries of the transgenic mice were approximately one half the size of the control strain and appeared to be inactive. The corpora lutea and follicles which should normally be present were visually absent from the hGH transgenic strain.

Individual oviducts from transgenic and normal mice were weighed and recorded (Table 1). These wet weights show that statistically there is no difference between the weights of oviducts from normal and the Interferon transgenic litter mates or between normal and the hGH transgenic litter mates. Furthermore, there was no statistical difference between the two groups of mice in this measurement.

The amount of protein per oviduct was estimated using the method of Lowry et al., (1951) relative to a BSA standard. The total amount of protein (ug) per oviduct was found to be statistically different between the transgenic hGH group and the oviducts from the ± Interferon group, but not different from the hGH litter mates (Table 1). This suggests that the hGH gene does not change the ratio between the wet weight of a tissue and the protein content of that tissue.

However, when the data were normalized as ug protein per mg oviduct wet weight the values within each group were not significantly different from each other. The value for the transgenics expressing the Interferon gene appeared to be significantly smaller than the value for the controls from hGH group but not the transgenic litter mates expressing the hGH gene. However, no significant differences were observed between these two groups when only total protein per oviduct was calculated. Finally specific activities of the lactate dehydrogenase

were calculated and reported in Table 2 as umoles of product formed/min/mg protein. The specific activities of control and transgenic interferon litter mates were found to be statistically similar as were the control and transgenic hGH litter mates. However, there was a difference in specific activities between these two groups. The group ± Interferon had approximately 30% more activity than did the group ± hGH. This was an unexpected difference because weights of oviducts among the groups were not significantly different.

DISCUSSION

These enzyme experiments were performed in oviducal tissue in order to determine if LDH activity is modulated in transgenic mice relative to control litter mates. From other studies (Patterson and Masters, 1972; Farley et al., 1990) it has been demonstrated that the specific activities of oviducts, at all reproductive stages studied, are considerably higher than the values found in uterine tissues. In addition, the specific activities change in response to the reproductive state of the animal (Farley et al.,1990; Nieder and Corder, 1983). Since embryos are considerably dependent upon the lactate and pyruvate in their environment (Georgiev et al., 1970), especially in the oviduct, LDH is considered to have some effect on successful reproduction. In this study, LDH was easily detected in the transgenic and normal mouse individual oviducts. The specific activities of LDH in mouse oviducts (Table 2) show that among litter mates there was no difference; however, between groups there clearly was a difference. These results are quite surprising in view of the facts that the wet weight of oviducts between groups and within the same group, with and without the foreign gene, were not significantly different. In addition, the hGH mice were much larger (total body weight) than either their litter mates or the ± Interferon group (Bartke, et al., 1988). Total protein per oviduct does show a difference between the groups. These data suggest that the specific activities of enzymes are probably the best way to compare results between groups, tissues, and other variables when using animals to study enzymic reactions.

The results from the transgenics receiving the hGH gene are rather surprising especially in view of the fact that the animals are substantially larger than their litter mates. We had anticipated that the reproductive organs would reflect some change in size. Shea et al.(1987) report that, in transgenic mice expressing growth hormone genes, some organs, such as spleen, kidney, and liver, increased in size in proportion to the increase in body weight. However, they did not evalute reproductive tissues. Our data have implications for the reproductive capabilities of transgenic versus normal litter mates. Since there are few changes in the size of the reproductive organs, the apparent amount of proteins, or the activity of one specific enzyme, LDH, one would anticipate few reproductive problems with these transgenic mice. This is, however, not always the case since Bartke et al. (1988) report a decrease in the fertility of female hGH transgenics. Transgenic animals produce potentially fertile eggs, mate, and yet fail to become pregnant. Bartke et al. (1988) attribute the infertility to luteal deficiency. Possible abnormal oviduct function could also contribute to reproductive failure. Our lack of differences in the specific activities of LDH, however, argues against this activity being involved with the sterility of

transgenics. In addition, we suggest that when using transgenic mice it is important to carefully compare litter mates of mice used in the investigation as it may be difficult to compare data between groups.

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Table 1. Wet weights and protein values of mouse oviducts*

GROUP	N	µMOLES/MIN/mg PROTEIN (Mean±SD)
- Interferon	5	0.320±0.001a
+ Interferon	10	0.299±0.046a
- hGH	7	0.227±0.058b
+ hGH	7	0.191±0.025b

N = number of animals

values with the same letter are not significantly different ($p<0.05$)

Table 2. Specific activies of LDH in mouse oviducts

GROUP	N	WET WEIGHT(mg) OVIDUCT	TOTAL PROTEIN OVIDUCT (µg)	µg PROTEIN mg OVIDUCT
- Interferon	10	3.40 ± 0.84^{a}	230 ± 29.6^{b}	72.8 ± 27.1^{de}
+ Inteferon	20	3.85 ± 1.27^{a}	233 ± 76.8^{b}	60.1 ± 17.1^{d}
- hGH	14	3.64 ± 1.69^{a}	281 ± 158^{bc}	80.6 ± 47.5^{e}
+ hGH	14	4.14 ± 12.3^{a}	322 ± 88.3^{c}	80.5 ± 19.7^{de}

* MEAN ± SD

N = number ofoviducts

values with the same letter are not significantly different ($p<0.05$)

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Distribution, Abundance, and Habitat of the Marsh Rice Rat (*Oryzomys palustris*) in Southern Illinois

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ABSTRACT

1. Live-trapping was conducted at sites in 17 southern Illinois counties during 1986 and 1987 to determine the distribution of the state-threatened marsh rice rat (*Oryzomys palustris*). 2. A total trapping effort of 3517 trap-nights resulted in 1111 captures of small mammals representing 13 species. 3. Rice rats were caught at 13 sites in ten counties, including four (Hamilton, Pope, Saline, and White) from which this species had not been previously reported. 4. Although at least 99 rice rats were captured, the number of individuals caught at most trapping sites was five or fewer. 5. Rice rats were found in permanent or ephemeral wetlands with emergent herbaceous vegetation. 6. Such habitats typically exist as small, isolated patches that cannot support large populations. 7. Further loss of habitat is the major threat to this species in Illinois and its continued status as a state-threatened species appears to be warranted.

INTRODUCTION

The marsh rice rat (*Oryzomys palustris*) is the only member of this predominantly Neotropical genus with an extensive range in the United States (Honacki *et al.* 1982). Its range extends from extreme southeastern Texas north to southeastern Kansas, through the southeastern states to Florida and north along the Atlantic seaboard to Pennsylvania and New Jersey (Wolfe 1982). A recent taxonomic revision of the species recognizes two subspecies: *O. p. palustris* in the continental United States and *O. p. natator* in peninsular Florida (Humphrey and Setzer 1989). Southern Illinois is at the northern limit of the range of *O. p. palustris*. The distribution, abundance, and life history of the rice rat in Illinois are not as well known as elsewhere (Wolfe 1982). Specimens have been recorded from only a few localities in the southernmost portion of the state.

As a result, the rice rat has been designated as a threatened species in Illinois (Illinois Administrative Code, Title 17, Chapter I, subchapter c, part 1010.30, 17 March 1989).

Rice rats once ranged at least as far north in Illinois as Peoria County (Fig. 1), where their remains have been identified from an archaeological site (Baker 1936). Remains of rice rats have also been discovered in Indian midden materials and paleontological deposits in Calhoun, Fulton, Greene, Madison, Pike, Randolph, St. Clair, Sangamon, and Scott counties (Fig. 1; Purdue and Styles 1986). During the Holocene, fluctuations in climate and the resulting changes in vegetation have caused shifts in the distributions of several mammalian species in Illinois. Southern species, such as the rice rat, extended their ranges northward during episodes of warmer climatic conditions, *i.e.* the Atlantic Episode (8500-5100 years BP) and the Scandic to Pacific Episodes (1700-400 years BP). The onset of cooler conditions again in the Neo-Boreal (400 years BP) apparently limited the range of the rice rat to the southernmost portion of Illinois (Purdue and Styles 1986).

The earliest modern records of rice rats in Illinois were from the towns of Olive Branch and Cache in Alexander County (Cory 1912; Necker and Hatfield 1941). McLaughlin and Robertson (1951) collected two specimens in southeastern Johnson County and concluded that rice rats were limited to swampy areas south of the Ozark Uplift, *i.e.* within the Coastal Plain Division of Schwegman (1973). More recently, rice rats have been reported from Franklin, Jackson, Massac, Pulaski, Union, and Williamson counties (Klimstra and Scott 1956; Klimstra 1969; Klimstra and Roseberry 1969; Rose and Seegert 1982; Urbanek and Klimstra 1986; Illinois Natural Heritage Database [INHD]). In addition, the remains of a rice rat were found in the stomach of a mink (*Mustela vison*) collected from an unspecified location in Washington County (Casson 1984). The recent range of the rice rat in Illinois, inferred from these limited records, extends through the Ozark, Lower Mississippi River Bottomlands, and Shawnee Hills divisions into the Mt. Vernon Hill Country Section of the Southern Till Plain Division (Schwegman 1973). Localities from which rice rats have been collected in Illinois exclusive of the present study are shown in Fig. 1.

The rice rat is semiaquatic, preferring wetland and riparian habitats. Rice rats are known to occur in salt and freshwater marshes, swamps and wet meadows, and along streams, ditches and lake shores (Barbour and Davis 1974; Hamilton and Whitaker 1979; Schwartz and Schwartz 1981; Wolfe 1982; Webster *et al.* 1985; Wolfe 1985; Jones and Birney 1988; Hoffmeister 1989). Such areas are often subject to human-induced alterations, primarily channelization or drainage. Rice rats occasionally are found on dry upland slopes (Schwartz and Schwartz 1981), but such individuals may be transients (Wolfe 1982). The major habitat requirement for this species appears to be a dense ground cover of grasses, sedges, or shrubs (Barbour and Davis 1974; Hamilton and Whitaker 1979; Schwartz and Schwartz 1981). The habitats where rice rats previously were captured in Illinois have been described as follows: a lowland brome-grass meadow; a wet forest-grass area; an agricultural drainageway containing native and non-native grasses; a cypress swamp; a marshy railroad right-of-way; a reed (*Phragmites australis*) marsh on surface-mined land; a low-lying successional field; and a farm pond dam (McLaughlin and Robertson 1951; Klimstra and Scott

1956; Klimstra 1969; Klimstra and Roseberry 1969; Urbanek and Klimstra 1986; INHD). More specific information on the characteristics of habitats that support rice rats in Illinois is lacking.

The primary objective of this study was to investigate the current distribution of the rice rat, but information on the abundance and habitat of this species was also obtained. Such information is essential for evaluating the status of the rice rat as a threatened species in the state and as a basis for conducting environmental assessments and developing recommendations for the management of rice rat populations.

METHODS

During June, October, and November 1986 and March through September 1987, live-trapping was conducted in 17 southern Illinois counties (Fig. 2). Most trapping sites were chosen during a study of the distribution of the rice rat funded by the Illinois Endangered Species Protection Board. After U.S. Geological Survey 7.5' topographic quadrangles and wetland maps generated by the Illinois Geographic Information System had been checked, sites were located by driving through a county looking for types of habitat known to be used by rice rats, such as thickly vegetated stream banks, ditches, or marshes. Other potentially suitable sites were trapped at the request of the Bureau of Location and Environment, Illinois Department of Transportation.

At least one site was located in each of the southernmost Illinois counties (Gallatin, Hamilton, Hardin, Perry, Pope, Randolph, Saline, and White) from which rice rats had not been reported previously. In addition, suitable habitat in Alexander, Franklin, Jackson, Johnson, Massac, Pulaski, Union, Washington, and Williamson counties was sampled to determine the current occurrence and abundance of the rice rat. Trapping sites in these latter counties were not locations from which rice rats had previously been recorded, because these sites were usually impossible to identify from available information.

Each study site was characterized in terms of its physiographic features, community type, and common plant species. At each site, trap lines were established with trap stations located at 10-m intervals. One Sherman live trap (8 x 9 x 23 cm) was placed on the ground at each station. Since the size of the areas of suitable habitat differed, the number of trap lines and stations varied among sites. Traps were baited with a mixture of rolled oats or wheat and peanut butter. During cold weather a small amount of cotton or polyester fiber was placed in each trap to provide warmth. Live-trapping was conducted for two consecutive nights in each county (although some individual trap lines were used for only one night). Traps were set during late afternoon or evening and checked early the following morning; they remained closed (unset) during the day.

The following information was recorded for each animal captured: trap station, species, sex, reproductive condition, and weight (to the nearest gram). The position of the testes (either descended into the scrotum or abdominal) was used as a general indicator of male reproductive condition. Females were examined for such signs of reproductive activity as a perforate vagina, pregnancy (determined by palpation of the abdomen), or lactation (determined by inspection of the teats).

In order to recognize individuals that were recaptured on the second morning of a trapping session, animals caught on the first morning were marked. A small patch of fur was clipped on the back of each rice rat; members of other species were toe-clipped (only one toe removed). After animals had been examined and marked, they were released at the trap station.

RESULTS

Trapping Results

A total trapping effort of 3517 trap-nights (one trap-night = one trap set for one night) resulted in 1111 captures of small mammals, an overall trapping success of 31.6%. Trapping success ranged from 69.1% in roadside ditches near Horseshoe Lake, Alexander County, to 3.3% along the backwaters of Big Creek, Hardin County. At least 941 individuals of thirteen species, two insectivores and eleven rodents, were caught. In addition to the rice rat, other species caught were the southern short-tailed shrew (*Blarina carolinensis*), least shrew (*Cryptotis parva*), eastern chipmunk (*Tamias striatus*), golden mouse (*Ochrotomys nuttalli*), white-footed mouse (*Peromyscus leucopus*), deer mouse (*P. maniculatus*), prairie vole (*Microtus ochrogaster*), pine vole (*M. pinetorum*), southern bog lemming (*Synaptomys cooperi*), house mouse (*Mus musculus*), Norway rat (*Rattus norvegicus*), and meadow jumping mouse (*Zapus hudsonius*). The white-footed mouse was the most commonly encountered species (587 individuals).

Rice rats were captured at 13 trapping sites in ten counties (Table 1, Fig. 2). They were found for the first time in Hamilton, Pope, Saline, and White counties and were also trapped at new localities in six counties for which previous records exist (Alexander, Franklin, Jackson, Johnson, Massac, and Williamson). Rice rats were not caught in Pulaski, Union, or Washington counties even though the species had been reported there previously. Despite the trapping efforts reported here, no rice rats have been captured in Gallatin, Hardin, Perry, or Randolph counties.

The 132 captures of rice rats represented 99 to 103 individuals (Table 2). The number of individuals is inexact because of uncertainty about the number of recaptures at the Saline County site. During the second night of trapping, the water level rose unexpectedly, inundating some traps and making it difficult to determine if wet animals had been marked. Breeding populations, as indicated by the presence of reproductively active females, occurred at seven trapping sites in seven counties (Table 2).

Although at least 99 rice rats were trapped during this study, nearly half (45-49 individuals) were captured at the Saline County site and more than 70% (72-76 individuals) were caught at just four sites in Alexander, Jackson, Pope, and Saline counties. Five or fewer rice rats were caught at each of the nine remaining sites (Table 2). Although the numbers of rice rats captured at these nine sites were low, the relative abundances (number of individuals captured per 100 trap-nights) for this species varied considerably (Table 2). For example, at a strip-mine pond in Williamson County only one individual was caught in 120 trap-nights for a relative abundance of 0.83. In contrast, at a roadside ditch in Hamilton

County five rice rats were caught in only 22 trap-nights, a relative abundance of 22.73.

Additional trapping information for each site where rice rats were captured is given in the Appendix.

Habitat Features

According to the categories defined by the National Wetland Inventory Program (U.S. Fish and Wildlife Service), habitat at sites where rice rats were captured during this study would be classified as palustrine emergent wetlands (PEM), palustrine scrub-shrub wetlands (PSS), palustrine aquatic beds (PAB), or riverine aquatic beds (RAB) (Table 1; Cowardin *et al.* 1979). The two types of site at which rice rats were most frequently captured during this study were ditches along county or state highways and the shorelines of lakes or ponds (Table 1). Rice rats were trapped in palustrine emergent wetlands in roadside ditches at five sites in four counties (Alexander, Franklin, Hamilton, and White; Fig. 3). They were found within emergent vegetation along the shores of Mermet Lake (Massac County), Norris City Reservoir (White County; Fig. 4), a pond created by subsidence as a result of underground mining (Saline County), and a tailing pond on surface-mined land (Williamson County).

Most sites where rice rats were caught during this study had two common features: standing water and emergent herbaceous vegetation (Fig. 3, 4). Rice rats were caught in two locations, however, that did not fully match this description. The first was the roadside ditch along county highway 7 in Hamilton County. Although standing water was absent at the time of trapping, the presence of saturated soil indicated that the ditch had been inundated earlier in the spring. The second exception was the capture of a single rice rat in a trapline at the edge of a forested palustrine wetland at Bay Creek in Pope County. This individual, however, was caught only 65 m from a scrub-shrub wetland on the opposite side of the creek that contained standing water and emergent herbaceous vegetation. Six other rice rats trapped at this site were within the scrub-shrub wetland.

The vegetation at all sites where rice rats were captured was characteristic of wetlands (Reed 1988) with representatives present from at least one, and often three or four, of the following groups: sedges (*Carex* spp.), bulrushes (*Scirpus* spp.), rushes (*Juncus* spp.), spike rushes (*Eleocharis* spp.), and cat-tails (*Typha* spp.). Rice cutgrass (*Leersia oryzoides*) occurred at three trapping sites and common reed (*Phragmites australis*) at two sites. Other grasses and a variety of terrestrial and aquatic broad-leaved plants also occurred at sites where rice rats were caught, but no single species or taxon seemed to be an indicator of habitat suitability. Wetland plants (obligate and facultative wetland species; Reed 1988) at each trapping site where rice rats were caught are listed in the Appendix.

DISCUSSION

Distribution

New records for Hamilton, Pope, Saline, and White counties obtained during this study reveal that the rice rat occurs substantially farther northeast in Illinois than indicated by previous records. Rice rats may have expanded their range within the state, perhaps using waterways and wet areas within highway and railroad rights-of-way as dispersal corridors. Even more likely, however, rice rats may have been present in these four southeastern Illinois counties but were unreported due to limited sampling. In fact, few museum specimens of such common species as *Peromyscus leucopus*, *Microtus ochrogaster,* and *Mus musculus* have been collected in Hamilton and White counties (Hoffmeister 1989).

The significance of the single rice rat specimen from the stomach contents of a mink taken at an unspecified location in Washington County (Casson 1984) is not evident. Furthermore, there are no records of rice rats from adjacent counties. It seems unlikely, therefore, that rice rats are widely distributed in Washington County. Although some potentially suitable habitat for rice rats occurs in Perry, Randolph, and Washington counties, the results of this study suggest that the primary range of this species extends only as far north as Franklin and Jackson counties in southwestern Illinois.

Rice rats were not caught in Pulaski or Union counties during this study and existing records do not suggest that the rice rat is common in either county. The only specimen known from Pulaski County was found dead in a field in January 1987 (INHD), and no rice rats have been reported from Union County since 1958 (Klimstra and Roseberry 1969). Although rice rats were captured in all adjacent counties during this study, if they were also present in Pulaski and Union counties, they would probably be uncommon due to the limited amount of suitable habitat.

Rice rats have never been captured in Gallatin and Hardin counties, although they were caught in adjacent counties during the present study. Their apparent absence from Gallatin and Hardin is probably attributable to the scarcity of suitable habitat. A comparison of conditions during 1986 with those shown on older U. S. Geological Survey quadrangles (New Haven SW, 1964 and Wabash Island, 1981) revealed that large expanses of wetland in Gallatin County have been drained for agricultural use.

Previous records indicated that the range of the rice rat in Illinois extended northward along the Mississippi River and through the Shawnee Hills along the Big Muddy and Cache River drainages. Habitat in the Saline River drainage and along the Ohio River north of Golconda had been considered unsuitable for this species (Klimstra and Scott 1956) until a rice rat was caught in the Saline River valley in 1975 (Urbanek and Klimstra 1986). During the present study, rice rats were captured not only in the Saline River valley but for the first time in the Little Wabash River drainage within Schwegman's (1973) Wabash Border Division of Illinois.

Habitat, Abundance, and Status

Although standing water and emergent herbaceous vegetation were characteristic of sites where rice rats were found in this study, these conditions did not ensure rice rat captures. No rice rats were caught at palustrine emergent or scrub-shrub wetland with standing water in eight counties (Gallatin, Hardin, Jackson, Perry, Pulaski, Union, Washington, and Williamson counties; Table 3). Because the rice rat is uncommon in Illinois and southern Illinois' wetlands are widely scattered, it is not surprising that areas of apparently suitable habitat have not been colonized. Some sites where rice rats were not captured during this study lacked standing water at the time of trapping (Hardin, Randolph, and White counties; Table 3). Other sites were forested palustrine wetlands (PFO) where herbaceous vegetation occurred atop stream banks but not in the water (Alexander, Johnson, and Union counties; Table 3). The results of this study strongly suggest that optimal habitat for rice rats in southern Illinois has standing water with emergent herbaceous wetland vegetation, but the possibility that rice rats occur in other types of habitat cannot be ruled out.

Mermet Lake in Massac County, Norris City Reservoir in White County, Worthen Bayou in Jackson County, and the Saline County wetland are permanent bodies of water where rice rats were captured. Other sites where rice rats occurred during this study, however, contained standing water, but only seasonally or semipermanently (*e.g.*, roadside ditches in Alexander, Hamilton, and White counties). Although rice rats occupied such ephemeral wetland areas, they may not use them year-round (Hofmann and Morris, unpublished data). During drier seasons (or drought years) they would be likely to move to other suitable habitat, perhaps to more permanent sources of water. In the Everglades, for example, rice rats occupy hammocks surrounded by water during the wet season but leave the hammocks during the the dry season, presumably moving to mesic sites (Smith and Vrieze 1979). By the same reasoning, study sites that had no standing water at the time of trapping might be occupied by rice rats at other times.

The results of this study indicate that rice rats are not limited to natural, undisturbed wetlands. For example, rice rats were often found in wetland habitat in roadside ditches. Such ditches receive and may retain water from direct precipitation, surface runoff, and agricultural drainage. Standing water may, therefore, be present at least seasonally, resulting in the establishment of wetland vegetation. Other habitats created or altered by humans where rice rats were found during this study included a channelized drainage ditch (Worthen Bayou, Jackson County) and a tailing pond on surface-mined land (Williamson County)

The sizes of the wetland sites that were inhabited by rice rats during this study were estimated using field notes, U. S. Geological Survey 7.5' quadrangles, National Wetland Inventory maps, and Agricultural Stabilization and Conservation Service (U. S. Department of Agriculture) aerial photographs. The largest areas were the palustrine emergent wetlands in Saline County (approximately 5.5 hectares) and along the shoreline of Mermet Lake (approximately 4.5 hectares). Eight of the 13 sites, however, were estimated to have been one hectare or less in size. The smallest areas found to be inhabited

by rice rats, two roadside ditches in Hamilton County, were approximately 0.1 and 0.03 hectare. Thus, the size of a wetland does not limit the occurrence of this species.

Although the amount of habitat considered to be suitable for rice rats at each site could be estimated, the area that was effectively sampled by trap lines could not be determined. As a result, population densities were not calculated. The relative abundance of rice rats at each site, however, was calculated (Table 2); these values should correlate with density and be useful for comparisons among sites (Emmel 1976). Relative abundances suggest that high densities of rice rats occurred at several sites, but large numbers of individuals (>10) were captured only in Alexander and Saline counties. At the other sites, the absolute number of individuals captured was small, a reflection of either low densities (e.g., a Williamson County pond where only one rice rat was caught in 120 trap-nights) or limited size of suitable habitat (e.g., Hamilton County).

Although rice rats were captured in ten Illinois counties, the major difficulty encountered during this study was locating potentially suitable rice rat habitat. Many wetlands in southern Illinois no longer exist due to surface mining, residential and commercial development, highway construction and, most often, drainage for agriculture. The remaining wetland areas often are small, disjunct, and ephemeral and are unable to support large numbers of rice rats. Small populations are especially vulnerable to extirpation due to environmental changes, disease, or predation. Furthermore, if a local population were extirpated, recolonization of the area could be slow or nonexistent because the large expanse of unsuitable habitat would act as a barrier to other populations.

In conclusion, the continued listing of the rice rat as a threatened species in Illinois appears warranted. This species may be limited in its distribution by climatic factors to the southernmost portion of the state and it may never be considered common even there. Suitable habitat is limited and further habitat loss appears to be the major threat to the continued existence of rice rats in Illinois. Remaining wetlands, especially palustrine emergent and palustrine scrub-shrub wetlands, should be protected and serious consideration should be given to the restoration and creation of wetlands within the range of this species.

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APPENDIX

Alexander County

Trapping dates: 30-31 March 1987
Trap-nights: 188
Trapping success: 69.1%
Mammal species[a]: *Microtus ochrogaster* (11 individuals), *Ochrotomys nuttali* (1), *Peromyscus leucopus* (86)
Wetland plants[b]: *Arundinaria gigantea, Asclepias incarnata, Carex scoparia, C. squarrosa, C. vulpinoidea, Elymus virginicus, Fraxinus pennsylvanica, Liquidambar styraciflua, Lycopus americanus, Polygonum hydropiperoides, Quercus palustris, Scirpus atrovirens, Spermacoce glabra, Stachys tenuifolia*

Franklin County

Trapping dates: 12-13 May 1987
Trap-nights: 142
Trapping success: 32.4%
Mammal species: *Microtus pinetorum* (1), *Peromyscus leucopus* (21), *Tamias striatus* (4-5), *Zapus hudsonius* (2)
Wetland plants: *Alisma plantago-aquatica, Amsonia tabernaemontana, Carex annectens, C. hyalinolepis, C. squarrosa, Eleocharis tenuis, Galium obtusum, Iris brevicaulis, Juncus torreyi, Scirpus atrovirens, S. pendulus, Typha latifolia*

Hamilton County: county highway 7

Trapping dates: 3-4 June 1987
Trap-nights: 80
Trapping success: 65.0%
Mammal species: *Microtus ochrogaster* (2), *Mus musculus* (17), *Peromyscus leucopus* (12)
Wetland plants: *Carex annectens, C. frankii, C. lupuliformes, C.* c.f. *scoparia, C. typhina, Glyceria striata, Juncus acuminatus, J. effusus, Leersia oryzoides, Sagitarria* sp., *Scirpus validus, Typha latifolia*

Hamilton County: Illinois Route 14
Trapping dates: 3-4 June 1987
Trap-nights: 22
Trapping success: 72.7%
Mammal species: *Mus musculus* (9), *Peromyscus leucopus* (1), *P. maniculatus* (1)
Wetland plants: *Carex annectens, C. frankii, C. vulpinoidea, Glyceria striata, Juncus brachycarpus, J. marginatus, Scirpus atrovirens, S. pendulus, S. validus, Typha latifolia*

Jackson County
Trapping dates: 23-24 September 1987
Trap-nights: 72
Trapping success: 27.8%
Mammal species: *Mus musculus* (7), *Peromyscus leucopus* (2), *P. maniculatus* (1)
Wetland plants: *Ammania coccinea, Bidens* sp., *Cyperus erythrorhizos, Leersia oryzoides, Ludwigia decurrens, Polygonum lapathifolium, Rotala ramosior*

Johnson County: site 1
Trapping dates: 1-2 April 1987
Trap-nights: 86
Trapping success: 20.9%
Mammal species: *Microtus ochrogaster* (5), *Peromyscus leucopus* (9)
Wetland plants: *Arundinaria gigantea, Asclepias incarnata, Hibiscus moscheutos, Iris fulva, Ludwigia alternifolia, Lythrum alatum, Scirpus cyperinus*

Johnson County: site 2
Trapping dates: 2 April 1987
Trap-nights: 26
Trapping success: 15.4%
Mammal species: *Peromyscus leucopus* (2)
Wetland plants: *Hibiscus moscheutos, Impatiens capensis, Juncus* sp., *Salix nigra*

Massac County
Trapping dates: 1-2 April 1987
Trap-nights: 200
Trapping success: 28.5%
Mammal species: *Microtus ochrogaster* (1), *Mus musculus* (6), *Peromyscus leucopus* (39)
Wetland plants: *Nelumbo lutea, Polygonum lapathifolium, Senecio glabellus, Typha latifolia*

Pope County
Trapping dates: 2-3 June 1986
Trap-nights: 160
Trapping success: 25.6%
Mammal species: *Blarina carolinensis* (1), *Peromyscus leucopus* (28)
Wetland plants: *Acer saccharinum, Amorpha fruticosa, Betula nigra, Carex hyalinolepis, Celtis laevigata, Cephalanthus occidentalis, Chasmanthium latifolium, Fraxinus pennsylvanica, Ilex decidua, Ludwigia decurrens, Penthorum sedoides, Quercus palustris, Salix nigra*

Saline County
Trapping dates: 27-28 April 1987
Trap-nights: 200
Trapping success: 38.0%
Mammal species: *Microtus ochrogaster* (2), *Mus musculus* (10)
Wetland plants: *Carex vulpinoidea, Phragmites australis, Salix nigra, Typha angustifolia*

White County: Illinois Route 1
Trapping dates: 26-27 May 1987
Trap-nights: 25
Trapping success: 24.0%
Mammal species: *Peromyscus leucopus* (3)
Wetland plants: *Acer saccharinum, Betula nigra, Carex* c.f. *lupulina, Cephalanthus occidentalis, Eleocharis obtusa, Hibiscus moscheutos, Juncus acuminatus, J. effusus, Salix nigra, Scirpus atrovirens, Typha latifolia*

White County: Norris City Reservoir
Trapping dates: 27 May 1987
Trap-nights: 15
Trapping success: 60.0%
Mammal species: *Mus musculus* (4), *Rattus norvegicus* (1)
Wetland plants: *Carex vulpinoidea, Cephalanthus occidentalis, Glyceria striata, Ludwigia peploides, Salix nigra, Typha latifolia*

Williamson County
Trapping dates: 7-8 April 1987
Trap-nights: 120
Trapping success: 11.7%
Mammal species: *Microtus ochrogaster* (1), *Peromyscus leucopus* (1), *P. maniculatus* (5), *Synaptomys cooperi* (2)
Wetland plants: *Phragmites australis, Typha latifolia*

[a] exclusive of *Oryzomys palustris*
[b] obligate or facultative wetland species (Reed 1988)

Figure 1. Localities where rice rats have been reported in Illinois exclusive of this study and their former distribution in the state based on archeological finds (Baker 1936; Necker and Hatfield 1941; McLaughlin and Robertson 1951; Klimstra and Scott 1956; Klimstra 1969; Klimstra and Roseberry 1969; Rose and Seegert 1982; Casson 1984; Urbanek and Klimstra 1986; Purdue and Styles 1986; INHD).

Figure 2. Locations of live-trapping sites in 17 southern Illinois counties, 1986 and 1987.

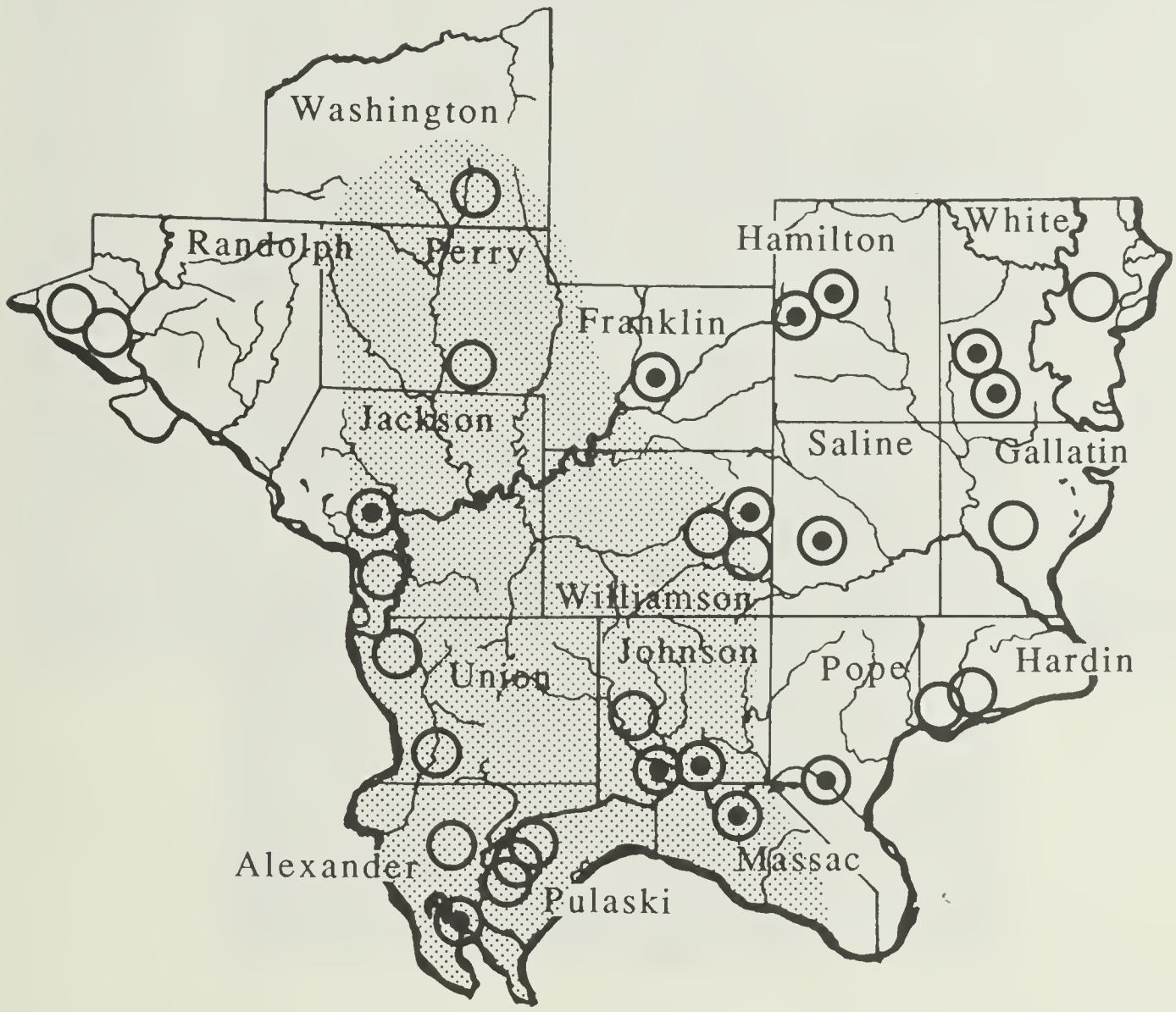

Figure 3. Ephemeral palustrine emergent wetland in a shallow roadside ditch in Franklin County, Illinois. Sedges, bulrushes, rushes, and spike rushes form a dense cover of herbaceous vegetation.

Figure 4. Confluence of Norris City Reservoir and a roadside drainage ditch, White County, Illinois. The water is partially covered with mats of creeping primrose-willow (*Ludwigia peploides*) and common cat-tail (*Typha latifolia*), rice cutgrass, and sedges grow along the water's edge.

Table 1. Locations and wetland classifications of trapping sites where *Oryzomys palustris* was captured in southern Illinois, 1986-1987.

COUNTY	TRAPPING SITE	LEGAL LOCATION	UTM COORDINATES	WETLAND TYPE[a]
Alexander	Roadside ditch, Promised Land Road 4.0 km NW Cache	T16S, R2W, Sec. 14, NE/4 and NW/4, SW/4	295450E 4110600N	PEM
Franklin	Roadside ditch, county highway 11 8.0 km SW Benton	T6S, R2E, Sec. 33, SE/4, SW/4 and T7S, R2E, Sec. 4, NE/4, NW/4	324100E 4202000N and 324100E 4201950N	PEM
Hamilton	Roadside ditch, county highway 7 2.5 km ENE Macedonia	T5S, R5E, Sec. 29, SE/4, NW/4 and NE/4, SW/4	325875E 4213540N	PEM
	Roadside ditch, Illinois Route 14 6.0 km W McLeansboro	T5S, R5E, Sec. 24, NE/4, NW/4	359360E 4215820N	PEM
Jackson	Worthen Bayou, west of Illinois Route 3 2.0 km SW Grimsby	T9S, R3W, Sec. 17, NE/4, SW/4	282900E 4179650N	PEM /RAB
Johnson	Marshy fields adjacent to Belknap Road			
	3.5 km NE Belknap	T13S, R3E, Sec. 32, SW/4, NW/4	330720E 4134680N	PEM
	4.0 km NE Belknap	T13S, R3E, Sec. 32, SW/4, NW/4	330980E 4134840N	PEM
Massac	Shore of Mermet Lake 2.5 km S Mermet	T14S, R3E, Sec. 35, NW/4 and SE/4, NE/4	336320E 4125340N and 336500E 4125200N	PEM
Pope	Bay Creek and associated wetlands 0.4 km S Brownfield	T13S, R5E, Sec. 36, NE/4, SE/4	357820E 4133940N	PSS/PFO
Saline	Pond and marsh adjacent to Illinois Route 13 5.0 km W Harrisburg	T9S, R5W, Sec. 13, SW/4, NE/4 and NW/4, SE/4	358800E 4177850N	PEM
White	Roadside ditch, Illinois Route 1 5.5 km NE Norris City	T6S, R8E, Sec. 12, SE/4, SW/4	387600E 4207750N	PEM
	Shore of Norris City Reservoir 1.0 km E Norris City	T6S, R8E, Sec. 22, SE/4, SW/4	384750E 4204600N	PEM/PAB
Williamson	Shore of strip-mine pond 3.5 km E Crab Orchard	T9S, R4E, Sec. 21, NE/4, NE/4	344700E 4177100N	PEM

[a] based on National Wetland Inventory (U.S. Fish and Wildlife Service); PFO = palustrine forested wetland, PSS = palustrine scrub-shrub wetland, PEM = palustrine emergent wetland, PAB = palustrine aquatic bed, RAB = riverine aquatic bed (Cowardin *et al.* 1979)

Table 2. Numbers, reproductive condition, and relative abundances of *Oryzomys palustris* captured at trapping sites in southern Illinois, 1986-1987.

COUNTY	NO. CAPTURES	NO. INDIVIDUALS	NO. MALES		NO. FEMALES		RELATIVE ABUNDANCE [c]
			Repro. [a]	Non-repro.	Repro. [b]	Non-repro.	
Alexander	18	12	4	2	3	3	6.38
Franklin	6	3	1	1	1	-	2.11
Hamilton (Illinois Route 14)	5	5	1	3	-	1	22.73
Hamilton (Co. hwy. 7)	4	3	1	1	1	-	3.75
Jackson (Worthen Bayou)	9	8	-	5	1	2	11.11
Johnson (Site 1)	3	3	-	3	-	-	3.49
Johnson (Site 2)	2	2	-	1	-	1	7.69
Massac	7	4	-	2	-	2	2.00
Pope	7	7	3	2	1	1	6.25
Saline	62	45-49 [d]	12	12	7	14	≥ 22.50
White (Illinois Route 1)	3	2	1	1	-	-	8.00
White (Norris City Res.)	4	4	1	1	2	-	26.67
Williamson	2	1	-	1	-	-	0.83
Totals	**132**	**99-103**	**24**	**35**	**16**	**24**	

[a] Scrotal testes
[b] Perforate vagina, pregnant, or lactating
[c] Relative abundance = (no. individuals/no. trap-nights) X 100
[d] Exact number unknown

Table 3. Locations, wetland classifications, and habitat characteristics of trapping sites in southern Illinois where *Oryzomys palustris* was not captured, 1986-1987.

COUNTY	LEGAL LOCATION	WETLAND TYPE[a]	HABITAT DESCRIPTION	HABITAT FEATURES Wetland Veg.[b]	Water[c]
Alexander	T15S, R2W, Sec. 13, NE/4	PFO	forested creek bank	Yes	Yes
Gallatin	T9S, R9E, Sec. 20, NW/4	PEM	marshy field	Yes	Yes
Hardin	T12S, R8E, Sec. 27, SW/4	PSS/PEM	shrubland and marsh	Yes	Yes
	T12S, R7E, Sec. 35, SE/4	PFO; PEM	forested creek bank; ditch	No; Yes	Yes; No
Jackson	T10S, R3W, Sec. 9, NW/4	PEM	roadside ditch	Yes	Yes
Johnson	T13S, R3E, Sec. 17, SW/4	PFO	forested creek bank	Yes	Yes
Perry	T6S, R2W, Sec. 17, NE/4	PEM	roadside ditch	Yes	Yes
Pulaski	T15S, R1W, Sec. 10, NE/4	PFO; PSS	forested creek bank; RR ditch	No; No	Yes; Yes
	T14S, R1W, Sec. 23, NE/4	PEM	marshy field	Yes	Yes
	T14S, R1W, Sec. 26, NE/4	PSS/PEM	roadside ditch	Yes	Yes
Randolph	T6S, R8W, Sec. 28, SW/4	PEM	marsh	Yes	No
	T6S, R9W, Sec. 1, NE/4	PEM/PSS	marsh	Yes	No
Union	T11S, R3W, Sec. 9, NE/4 and NW/4	PFO/PEM	edge of swamp	Yes	Yes
	T13S, R2W, Sec. 17, SW/4	PFO	forested ditch bank	Yes	Yes
Washington	T3S, R2W, Sec. 22, NE/4 and T3S, R2W, Sec. 23, NW/4	PEM	creek channel	Yes	Yes
White	T5S, R10E, Sec. 13, NW/4	PEM	marsh	Yes	No
Williamson	T9S, R4E, Sec. 22, NW/4	PEM	strip mine ponds	Yes	Yes
	T9S, R4E, Sec. 25, NW/4	PEM	strip mine ponds	Yes	Yes

[a] based on National Wetland Inventory (U.S. Fish and Wildlife Service); PFO = palustrine forested wetland, PSS = palustrine scrub-shrub wetland, PEM = palustrine emergent wetland (Cowardin *et al.* 1979)

[b] Presence of herbaceous obligate or facultative wetland species (Reed 1988)

[c] Presence of standing water at time of trapping

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Effects Of Roadside Management Practices On Bird Richness And Reproduction

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ABSTRACT

More attention is being given to managing highway rights-of-ways (ROW) for wildlife in Illinois as most of the remaining natural habitats have been greatly altered or eliminated. The Illinois Department of Conservation (IDOC) established a Roadsides for Wildlife Program to enhance the use of roadsides by wildlife (primarily nesting pheasants). The IDOC and Illinois Department of Transportation agreed to cooperate in some areas of the state to improve conditions for wildlife by reducing roadside mowing, by planting shrubs and trees and/or seeding brome/alfalfa within the ROW. The objectives of this study were to: 1) compare avifauna richness, nesting density and reproductive success among managed and unmanaged ROW areas; 2) determine the effect woody vegetation plantings have on avifaunal parameters and 3) compare densities among managed and unmanaged ROW's with previously reported values for similar habitat types (grasslands, fencerows) to assess the importance of ROW's as avifauna habitat.

Nine species of birds were recorded in the ROW. Of these, only one, the red-winged blackbird (*Agelaius phoeniceus*) was abundant. Managed plots (brome/alfalfa) have more birds (albeit red-winged blackbirds), greater species richness, and higher nesting densities than unmanaged (fescue) plots. Woody

vegetation within the ROW's increased abundance and nesting densities, but not species richness. Six species of birds nested in the ROW, however, 92.9% of all nests were red-winged blackbirds. Managed plots had a significantly higher nesting density than unmanaged plots. There was no difference in rates of reproductive success rates of birds in managed and unmanaged areas.

The roadside wildlife management practices initiated by IDOT have benefitted avifauna to a limited extent. In terms of wildlife habitat ROW's are not the panacea for loss of habitats throughout the state, and more efforts are needed to aid the declining songbird populations in the state. At present, only the red-winged blackbird, a generalist, is adapting to this relatively young evolutionary ecological niche.

INTRODUCTION

There is growing interest on the part of both public and government groups regarding both the harmful and beneficial effects of highway rights-of-way (ROW) and their management. Several authors (Joselyn et al. 1968, Leedy 1975, Michael et al. 1976, Adams and Geis 1981) have concluded that most people, including some wildlife biologists, do not recognize or appreciate the potential value of ROW's as wildlife habitat.

The exact amount of land used by highway ROW's in the United States is unknown, but a minimum estimate is around 20 million acres (8.4 million ha) (Leedy and Adams 1982). Nationwide there is an area nearly equal to the state of Illinois in highway ROW's. An area this large is worthy of serious consideration in wildlife management, but we must know which species will be benefitted or unaffected by the availability of roadside habitat.

Little effort has been directed at managing ROW vegetation specifically for wildlife (Leedy 1975, Machan 1975). Traditional maintenance procedures consist primarily of mowing, herbicidal spraying (Voorhees and Cassel 1980) and removal of woody vegetation. These procedures are selected primarily on the basis of their vehicle safety and "beautification." More imaginative roadside management practices, however, consider wildlife and advocate no or delayed mowing, seeding wildlife ground covers, and planting small trees and shrubs within the ROW. A complete management plan, however, should take into account both the public's safety and augmentation of habitat available to wildlife. Few studies have examined the effects different ground covers and shrub/tree plantings have on songbird populations within the ROW. The purpose of this study was to determine to what extent birds use ROW with differing wildlife cover.

STUDY AREA

The study area is located in northwestern Illinois (Whiteside County) along Interstate Highway 88 (I-88) between the cities of Rock Falls and Erie. I-88 is a 4-lane divided hiqhway that extends east-west across the northern state. Construction of the highway in Whiteside county began in 1973 and was completed in 1976. The study area, however, was opened to traffic in 1975.

Managed plots were seeded (1973-1976) to a hungarian brome (*Bromis inermis*) /alfalfa (*Medicago sativa*)) mixture and unmanaged plots were seeded

(1973-1976) to tall fescue (*Festuca elaitor*) (D. Wandell, IDOT, pers. comm.). Eight effective height measurements were taken randomly from each plot in May and August of both years and averaged. The average effective height (a measure of height density, Wiens 1969) was 36.1 cm and 8.8 cm for brome/alfalfa and fescue plots, respectively. Trees, shrubs and woody vines were planted between the entire I-88 ROW from Rock Falls to Erie from 1976 through 1985 (except 1977-79 and 1984) by IDOT personnel. The major species planted in decreasing order of abundance during those years included honeysuckle (*Lonicera* sp.; N=8,300), autumn olive (*Elaeagnus umbellata;* N=5,500), red pine (*Pinus resinosa;* N=3,500), gray dogwood (*Cornus racemosa;* N=3,000), and wild grape (*Vitis riparia;* 3,000). These woody coverings, however, were not equally represented in my study area. Shrubs were present in 6 of the 15 ROW plots (40%). The dominant (over 90%) shrub/tree within the ROW was honeysuckle. It made up less than 15% of the total cover in plots in which it occurred. The plantings were in double rows spaced approximately 2 m apart (east to west) and 1.5 m (north to south). Most of the honeysuckle was mature between 2 and 3 m tall. Wild grape was common along fencerows, but other woody vegetation plantings were in low abundance. Since the initial seeding, the ROW has not been mowed, with the exception of a 3.3 m wide (2 mower swaths) strip closest to the road edge.

The commonest adjacent habitat type was agriculture. Approximately 90% of the adjacent habitats between Rock Falls and Erie were rowcropped for either corn (*Zea mays*) or soybeans (*Glycina max*), much of it fall plowed. Three other habitat types were also categorized: wooded, brush seral, and wetland. The wooded habitat consisted of a long narrow (30 m) wide tract of abandoned railroad ROW (RROW) consisting of relatively young (< 50 yrs) woody trees. Black locust (*Robinia pseudoacacia*), hackberry (*Celtis occidentalis*) and black cherry (*Prunus serotina*) were the dominant tree species. Behind this RROW was an extensive rowcrop of corn. Brush seral was covered with shrubs (honeysuckle and hawthorn (*Crataegus* spp.)) with intermittent areas of grass (fescue and bluegrass (*Poa* spp.) and mature trees (boxelder (*Acer negundo*) and white ash (*Fraxinus americanus*). These areas were 60 m and 100 m wide, (perpendicular to the ROW) respectively. Fields behind these areas were seeded to corn. Wetland was characterized by borrow pits with shoreline covered with willows (*Salix* spp.), but usually having emergent vegetation such as cattails (*Typha* spp.) and sedges (*Carex* spp.).

METHODS

A total of 6,710 m of roadside was studied (8.5 ha managed and 6.7 ha unmanaged). Fifteen linear plots from the road edge to the fence line, (which was used to delineate the ROW from the adjacent habitat) along I-88 were surveyed for avifauna use between 3 April and 2 August in 1985 and 1986. This period included the peak nesting months for nearly all bird species likely to use roadsides (Graber and Graber 1963).

Plot lengths ranged from 120 to 900 m (x_{avg}=447). These lengths were chosen so as to correspond with associated adjacent habitat types. For example,

in the entire study area brush seral habitat bordered the ROW in only two locations (300 and 120 m long, respectively). Thus, brush seral total coverage was 420 m long. Similarly, wooded and wetland sections were selected (850 m and 1840 m, respectively). The majority of the plots were adjacent to agriculture (3,600 m) because it was the dominant adjacent habitat. Plot width (range 19.0-28.4 m, x_{avg}=22.5) varied according to the width of the ROW.

Bird Survey

The author conducted bird surveys 2-3 days each week from 3 April through 14 July and, thereafter, once a week until 2 August 1985 and 1986. Surveys were conducted by walking slowly along a transect line within the ROW, halfway between the road edge and fence line. Frequent stops were made to record data or to look and listen. All birds seen, heard or both, regardless of distance from the ROW, (estimates of distances were made of birds in adjacent habitat) were recorded if I thought they were using the roadside or adjacent habitat. Birds flying overhead were not counted unless I thought they were entering or leaving the adjacent habitat. Three-minute stops were taken at 75 m intervals to give shy birds a chance to be detected. Counts were made under conditions of good visibility, little or no precipitation, and winds < 19 km/hr. Surveys (92%) began within 15 minutes of local sunrise and continued for 4-4.5 hours (time required to complete at least half of the study plots).

Birds recorded on more than 3 censuses (after 1 May of both years) within the ROW or the adjacent habitats were considered as using either the adjacent habitat, the ROW, or both as nesting or foraging habitat. This procedure (i.e.,using > 3 censuses after 1 May to establish residency) was arbitrarily chosen to exclude infrequent visitors or transients from the list of breeding or potentially breeding species.

Nest Survey

The entire area between the road edge and fence line (ROW) was thoroughly searched for bird nests once or twice a week from 26 April through 1 August of both years with the aid of a field assistant(s). Nests were identified, the location plotted, nesting success rates were calculated, and the types of nest substrate recorded.

RESULTS

Number of Species

Thirty-nine bird species (Table 1) were recorded on more than 3 censuses after 1 May of both years and were considered to be breeding, foraging, or both in the ROW or adjacent habitats. The ROW plots had fewer species (N=9, 23.1%) than the adjacent habitats during the 2-year study (N=39; 100.0%.; Table 1).

Managed plots without woody cover (n=4) had more species (N=9) than unmanaged plots (n=3; N=4) (Table 2).These differences though were not significant (t=1.281, df=5, p>0.10). There was no significant difference (t=0.696, df=9, p>0.50) in number of species between plots with and without woody vegetation. Managed (n=3) and unmanaged (n=1) plots with shrubs had 9 and 3 species, respectively. These differences were not statistically tested as there was no replicate for fescue plots. It appears that the presence of woody vegetation increases the number of species within ROW.

Number of species/1000 m ROW surveyed was greater in adjacent habitats which had more vertical structuring. Although adjacent agricultural habitat had 18 species (wooded 25, brush seral 16, wetland 14) (Table 1) this I believe was due to a more intensive sampling effort (53.6% of all adjacent habitats were agricultural in contrast to 27.4% wetland, 12.7% wooded, and 6.3% brush seral). When the number of species is calculated per 1000 m of ROW surveyed brush seral and wooded habitats had significantly greater species diversity (x_{avg}=5.0 and 3.7 species, respectively) than wetland (x_{avg}=1.6) or agricultural x_{avg}=0.8) adjacent habitats (Student-Newman Keuls, p=0.05).

Numerical Abundance

Of the nine species of birds recorded in the ROW habitat, only the red-winged blackbird (*Agelaius phoeniceus*) was abundant (28 individuals/1000 m ROW). The other 8 species recorded the ROW were in low abundance, i.e., < 3 individuals per 1000 m ROW (Table 2).

Managed plots had significantly (t=3.371, df=7, p<0.01) more (x_{avg}=19.3) individuals per 1000 m of ROW's censused than unmanaged (x_{avg}=5.3) plots (Table 2). Similarly, plots with woody cover had significantly (t=5.356, df=11, p<0.01) more individuals (all species, but predominantly red-winged blackbirds) per 1000 m ROW's censused (x_{avg}=16.0) than non-woody plots (x_{avg}=10.0).

Six species of birds were recorded as having high abundance and were positively influenced (i.e., located within 20 m of ROW) by the edge habitat created between the ROW and the adjacent habitats. These species include the red-winged blackbird, common grackle (*Quiscalus quiscula*), song sparrow, (*Melospiza melodia*), american robin (*Turdus miqratorius*), common yellowthroat (*Geothlypis trichas*), and indigo bunting (*Passerina cyanea*) (Table 1). The red-winged blackbird was by far the most abundant bird in the study area (Table 1).

Nest Survey

During the 2-year investigation, 383 nests with at least 1 egg were found. The majority of all nests (84.5%.) were found beyond 15.1 m of the roadedge. Ninety-percent of all nests in woody vegetation were in honeysuckle. Eleven other woody species were used for nest construction. Only 6 species of birds nested in the ROW in 1985, and 5 of these (83.3%) nested there again in 1986. Of these, only 1 species, the red-winged blackbird, used the ROW

extensively (Table 3). There were significantly (X^2=25.504, p<0.01) more red-winged blackbird nests (N=356, 92.9%) within the ROW during the 2-year period than all other species combined.

Managed plots had significantly (t=3.78, df=14, p<0.01) more nest/ha than unmanaged plots (9.1 vs. 0.7, respectively; Table 3). Plots with woody cover had significantly (t=3.13, df=26, p<0.01) more nests/ha than non-woody plots (N=17.7 vs. 7.0, respectively). Moreover, shrub plots also had a greater diversity of nesting species (N=6) than grass plots (N=3).

Because the sampling sites were small for all bird species except red-winged blackbirds, reproductive success rates were calculated for the latter only. Reproductive success as defined by Smith (1943:195) is the ratio of young fledged to eggs laid. There was no statistical difference (p< 0.10) in reproductive success between red-wings nesting in woody vegetation (55.4%) or grass substrates (51.8%). Reproductive success could not be compared between managed and unmanaged plots as only 2 red-winged blackbird nests were found in the latter.

DISCUSSION

Number of Species

Previous roadside studies (Machan 1975, Roach and Kirkpatrick 1985) demonstrated that woody plantings within highway ROW's increase bird species diversity. Moreover, they showed that managed highway ROW's (i.e., with shrub and tree plantings) have greater species diversity than unmanaged roadsides. Machan (1975) observed 34 bird species in managed wooded plots in contrast to 20 species in grass plots along an Indiana ROW. Similarly, Roach and Kirkpatrick (1985) in Indiana observed 25 and 17 species in wooded and grass plots, respectively. In this study, however, shrub plots, which are the equivalent of managed plots, did not have significantly more species (N=9) than grass plots (N=7). The major reason for this discrepancy may be the lack of suitable adjacent cover in the study area. As mentioned previously, approximately 90% of the adjacent habitats in the study area were intensively rowcropped. The other studies did not have as much adjacent agricultural habitat and this may be why they were able to detect a difference. I suspect poor quality adjacent habitat is the main reason I did not detect any differences in number of species between managed and unmanaged plots.

Numerical Abundance

Plots with woody vegetation had significantly more birds than grass plots (Table 2). Several investigators have reported similar findings (Wandall 1948, Machan 1975, Arnold 1983, Best 1983, Roach and Kirkpatrick 1985). Machan (1975) and Roach and Kirkpatrick (1985) had 3.2 and 2.4 times more birds in woody than grass plots, respectively. My results agree with these previous studies as I found 1.6 times more birds in woody than grass plots. Thus, shrub

plantings within the ROW do increase the numerical abundance of birds (albeit mostly red-winged blackbirds) using this habitat.

In the absence of woody vegetation, managed plots had 3.6 times more birds than unmanaged plots. Similar findings have been reported by Warner (1985). Fescue is a traditional grass that many highway departments use to seed new sections of ROW. It is used because of its low cost, ease of establishment and erosion control benefits. Fescue is not a very dense growing grass; its average effective height was only 8.8 cm as compared to 36.1 for brome/alfalfa. Evidence from this study and those cited above document that fescue does not provide suitable avifauna cover. Roadside managers should discontinue seeding fescue along new sections of highway, and search for ways to attract birds in sections which have already been established to fescue (perhaps reseeding to brome/alfalfa).

Nest Survey

Only 6 species of birds nested in the ROW during the 2-year study. Previous investigators (Hengenrader 1962, Machan 1975, David and Warner 1981, Roach and Kirkpatrick 1985), however, reported at least 16 additional species of birds nesting within ROW's. In addition, at least 6 species of waterfowl (Oetting and Cassell 1971) and the Ring-necked Pheasant (Joselyn et al. 1968) are known to nest in ROW habitats. The above results indicate that managed highway ROW's can attract a relatively large diversity of nesting songbird species. I suspect the main reason for low diversity of nesting birds in my area was due to adjacent habitats largely being agricultural rowcrops. This leads me to believe that species abundance and diversity in ROW's are largely a function of the quality of adjacent habitat. Warner (1979) recognized that ROW management for wildlife in Illinois may depend on whether suitable adjacent cover, such as small grain or hay is present. It would be interesting to see if nesting diversity is correlated with quality of adjacent habitat.

For example, red-winged blackbird nests comprised 92.9% of all nests found during the 2-year study. Warner (1980, 1981) found that 85-95% of the songbird nests along two interstate ROW's adjacent to rowcrops in east-central Illinois were those of red-winged blackbirds. Roach and Kirkpatrick (1985) reported approximately 60% of the songbird nests in an Indiana ROW were red-winged blackbirds. Based on the above studies, it appears that only the red-winged blackbird will utilize ROW habitat extensively for nesting.

I found 383 nests of 6 species of birds. Plots with woody vegetation averaged 17.7 nests/ha (16.1 nests/ha by red-winged blackbirds). Grass plots seeded to brome/alfalfa or fescue averaged 9.1 and 0.7 nests/ha, respectively (8.9 and 0.5 nests/ha by red-winged blackbirds). Narrow corridors can potentially harbor high densities of nesting birds (Shalaway 1985). Shalaway (1985) reported 43.5 nests/ha in fencerow habitat in Michigan. Yahner (1982) reported 93.4 nests/ha in Minnesota shelterbelts; however, colonially nesting common grackles dominated those shelterbelts (50.5 nests/ha). In contrast to narrow corridors, Nolan (1963) reported 4.2 nests/ha in a natural deciduous shrub habitat in Indiana. Dambach and Good (1940) reported 1.2 breeding pairs/ha in pastures. Basore et al. (1986) reported 0.36 nests/ha in no-tilled fields and 0.04

in tilled fields in Iowa. My results corroborate Dow's (1969) conclusion that narrow habitat types, such as ROW's, can support relatively high densities of nesting birds. In my study area the results clearly show that only the red-winged blackbird is nesting in the ROW to any significant extent.

Extensive areas of narrow man-made ROW's have only been in existence for a brief period relative to the evolutionary time-scale. Therefore, perhaps these man-made situations are unrepresentative of the ecological niche in which most edge species have evolved (Gates and Gysel 1978), and thus they may be poorly adapted to cope with the linearly arranged habitat, increased noise and wind levels, and increased predation. Despite attempts to make ROW's attractive to birds it appears at present that only a generalist, such as the red -winged blackbird, is capable of nesting under these constraint conditions with any type of success.

Although it is difficult to generalize about the beneficial aspects of highway ROW's for avifauna it would appear that ROW's productivity is correlated with the quality of adjacent habitats. If adjacent habitats are sustaining healthy bird populations then there is little point in managing ROW's for avifauna adjacent to these areas. If, on the other hand, adjacent habitats are unconducive for supporting healthy bird populations, such as intensive rowcropping, then it would appear that managing ROW's for avifauna in these areas may not be maximized as most species cannot adapt to the narrow and linear dimensions that ROW's offer. Wildlife management must be analyzed case by case. In my study, I conclude that unless farming practices in this area change radically, managing and investing money into programs to aid birds within ROW's along I-88 can be better spent elsewhere.

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Table 1. Comparative numerical abundance (No. birds/1000 m ROW) for bird species considered breeding, foraging, or both, within the ROW or adjacent habitats.

	Habitat									
	ROW		Agricultural		Wetland		Brush Seral		Wooded	
Species[1]	1985	1986	1985	1986	1985	1986	1985	1986	1985	1986
Red-winged Blackbird	31.1	24.9	34.1	33.6	45.6	57.4	54.4	50.9	77.0	73.7
Common Grackle			0.7	0.9	7.5	8.0	9.8	8.2	14.2	15.1
Song Sparrow	0.2	0.1	3.7	1.8	8.6	10.9	10.4	13.1	12.2	11.4
American Robin	0.2	0.7	0.6	0.8	1.7	2.4	5.2	6.1	9.1	9.3
Common Yellowthroat					3.9	1.9	9.1	9.6	6.4	7.0
Indigo Bunting							8.5	9.2	3.1	5.2
Rock Dove					4.2	3.8			5.6	6.5
Gray Catbird							1.7	0.8	3.7	6.5
Cedar Waxwing									3.1	6.2
Tree Swallow					4.0	6.1			1.2	1.7
Barn Swallow			1.2	1.7	3.5	4.3	5.2	5.6	4.6	4.3
Blue Jay									5.5	2.9
Yellow Warbler					0.2	0.5	2.6	3.6	2.9	4.6
Northern Flicker							4.1	3.7		
Mallard	0.1	0.1	0.1		3.6	4.1				
Black-capped Chickadee									1.7	3.9
Northern Cardinal									2.6	3.5
Horned Lark			2.8	3.3						
Eastern Kingbird							3.0	1.6		
Brown-headed Cowbird			0.4					2.1	0.8	2.9
House Sparrow	0.2	0.2	1.1	0.6					1.4	2.5
Mourning Dove							2.5		1.5	2.2

Table 1. Continued

	Habitat									
	ROW		Agricultural		Wetland		Brush Seral		Wooded	
Species[1]	1985	1986	1985	1986	1985	1986	1985	1986	1985	1986
European Starling									2.2	1.5
American Goldfinch					0.5	0.3	2.2			
Brown Thrasher									1.9	
Great Blue Heron					0.2	1.7				
Chimney Swift			0.1				0.3	0.4	1.5	1.4
Dickcissel	0.1	0.2	1.5	1.4						
Rose-breasted Grosbeak									1.5	
Red-eyed Vireo									1.5	
Northern Oriole									1.2	1.0
Western Meadowlark		1.1		0.4						
Killdeer			0.6	1.0						
Eastern Meadowlark	0.5		0.3	0.2						
American Crow			0.3					0.5	0.4	
Swamp Sparrow					0.2					
Field Sparrow			0.2	<0.1	0.1					
Ring-necked Pheasant		0.1	0.1							
Chukar Partridge				0.1						
Subtotals by Year	7	8	15	12	14	12	14	14	25	21
Combined Totals	9		18		14		16		25	

[1]Listed in order of declining abundance.

Table 2. List of avifauna in order of declining abundance (No. birds/1000 m ROW) that were recorded in shrub vs. grass ROW's having either brome/alfalfa or fescue as the dominant ground cover type.

	ROW Habitat			
	---------- Woody ---------		------- Non-Woody ------	
Species	Brome/ Alfalfa	Fescue	Brome/ Alfalfa	Fescue
Red-winged Blackbird	29.9	10.9	25.2	9.4
Western Meadowlark	0.6	0.3	1.4	0.4
American Robin	1.4	---	---	---
Eastern Medowlark	0.4	0.3	0.3	0.1
Mallard	0.1	---	0.1	0.1
Song Sparrow	0.1	---	0.1	---
Dickcissel	0.1	---	0.1	---
Ring-necked pheasant	0.1	---	0.1	---
House Sparrow	0.1	---	---	---
Total No. of Species	9	3	7	4

Table 3. Bird nesting density by species within an interstate ROW in northwestern Illinois.

	ROW Habitat Type (#, nests/ha)		
	Shrub	Grass Type	
Species		Brome/Alfalfa	Fescue
Red-winged Blackbird	237 (16.1)	117 (8.9)	2 (0.5)
American Robin	16 (1.1)	0 (0.0)	0 (0.0)
Mallard	2 (0.1)	1 (0.1)	1 (0.2)
Common Grackle	3 (0.2)	0 (0.0)	0 (0.0)
Song Sparrow	2 (0.1)	1 (0.1)	0 (0.0)
Field Sparrow	1 (0.1)	0 (0.0)	0 (0.0)
Total	261 (17.7)	119 (9.1)	3 (0.7)

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The Emergence of a Specimen of *Psychomorpha epimenis* Drury (*Lepidoptera*) From a Goldenrod Ball Gall

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ABSTRACT

The emergence of a specimen of *Psychomorpha epimenis* Drury (*Lepidoptera*) from a goldenrod ball gall is reported.

DISCUSSION

A collection of goldenrod ball galls (N=88), made on March 27, l989 along a riverside path in Sylvan Island Park, Moline, Rock Island County, Illinois was separated into galls showing and not showing signs of predation. On April 3, l989 there emerged from one of the galls showing predation a specimen of *Psychomorpha epimenis*. The larva of this moth typically feeds on the terminal shoots of grape or Virginia Creeper early in spring (Comstock, l940). When it is ready to transform, usually towards the end of May, it enters the ground or bores into soft wood to form a chamber, where it remains until the following spring (Comstock, l940).

Downy Woodpeckers (*Picoides pubescens*), by burrowing tunnels, often prey upon insects within these tunnels (McAtee, l933; Uhler, l95l; Fischer, l974; and Terres, l980). Occurrence of this specimen is one of interest, since the tunnel in this particular gall was complete, thus indicating it has been preyed upon. It is suspected the *P. epimenis* larva entered the gall through a tunnel made a year earlier, in the spring of l988, and this gall was not preyed upon in l989. To my knowledge, this species has not yet been reported as using a goldenrod ball gall. The specimen is in the Augustana College insect collection.

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Location of Tunnels on Goldenrod Ball Galls Made by Downy Woodpeckers, *Picoides pubescens*

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ABSTRACT

Downy Woodpeckers (*Picoides pubescens*) predominantly excavate larvae from goldenrod ball galls by locating the epidermal cap at the surface of the tunnel made by the *Eurosta solidaginis* larva, and enlarging it.

DISCUSSION

The predatory activities of Downy Woodpeckers (*Picoides pubescens*) on goldenrod ball galls (McAtee, 1933; Uhler, 1951; Fischer, 1974; and Terres, 1980) can be readily observed in the field. There is disagreement among researchers as to the bird's method of tunneling into the gall in order to excavate the larva of *Eurosta solidaginis*. Uhler (1951) states that the woodpecker makes its tunnel into the central cavity of the gall at random, while Fischer (1974) suggests that it locates the epidermal cap at the end of the tunnel produced by the *E. solidaginis* larva, and enlarges this tunnel to gain access to the larva in the central cavity.

On March 27, 1989 goldenrod ball galls (N=88) were collected in Sylvan Island Park, Moline, Rock Island County, Illinois. Careful examination indicated that 72 (82%) were enlarged tunnels at the epidermal cap, and 16 (18%) were made from other directions. These observations seem to indicate that the predators predominantly enlarge existing tunnels, supporting the observations of Fischer (1974).

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Hematological Adaptation to Hypoxia in *Peromyscus* and *Microtus* at High and Low Altitude

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ABSTRACT

1. Values for hematocrit, hemoglobin, RBC numbers and diameter, MCH, MCV, and MCHC were obtained from native populations of *Microtus*, a semi-fossorial rodent, and *Peromyscus*, a non-fossorial rodent, at high and low altitude. Our objectives were to assess hematological adaptation to hypoxia, and to determine whether semi-fossoriality resulted in preadaptation to high altitude hypoxia.

2. There were no differences in the hematological parameters between *Microtus* species at low altitude.

3. Within each genus, high-altitude species had significantly greater hematocrits than their low-altitude congeners.

4. Comparison of the hemoglobin levels of high- and low-altitude animals showed significant differences within *Peromyscus*, but no significant differences within *Microtus*.

5. Erythrocyte numbers did not differ significantly within *Microtus*, regardless of altitude. *Peromyscus*, however, had significantly more red blood cells at 2900 m than at low altitude.

6. MCV increased with altitude within *Microtus* but not within *Peromyscus*. Mean values for MCHC were lower among high-altitude species.

7. These *Microtus* and *Peromyscus* respond differently to altitude; however, differences in these seven hematological parameters provided no

evidence for preadaptation to altitude hypoxia. Rather, these differences probably reflect alternative ways (increased hematopoiesis in *Peromyscus* versus altered red cell volume in *Microtus*) of solving the same problem of low environmental PO_2. This does not, however, preclude preadaption to hypoxia in some other blood parameter(s).

INTRODUCTION

Mammals may experience hypoxia on a day-to-day basis, either at high altitude or within a burrow. Adaptation to low ambient PO_2 may be reflected in the cellular components of the blood. Some mammals alter red blood cell numbers and volume in response to hypoxia (Armitage, 1983; Penney and Thomas, 1975; Hock, 1970; Bullard et al., 1966; Hurtado et al., 1945; Kalabuchov, 1937; Hurtado, 1932), but all species do not respond hematologically (Kalabuchov, 1937; Hall et al., 1936). Bullard (1972) postulated that burrowers may possess adaptive characteristics of the blood that enable them to immigrate into the hypoxic environment of high altitude. We wished to obtain hematological data on fossorial and non-fossorial genera whose ranges encompassed both high and low altitude environments.

The two genera of cricetid rodents used in this study, *Peromyscus* (deer mouse) and *Microtus* (vole) are found over a wide range of altitudes, from sea-level to 4350 m (Snyder, 1985; Hall, 1981). *Microtus* are semi-fossorial (Blair, 1968) whereas *Peromyscus* are chiefly surface-dwellers and non-fossorial (Lackey et al., 1985). Populations of *M. ochrogaster* and *M. pennsylvanicus* inhabit grasslands of the Midwest at elevations below 200 m, and occur sympatrically with *P. leucopus* (M'Closkey and Fieldwick, 1975; Dice, 1922). Populations of *P.maniculatus* and *M. montanus* occur at elevations above 2000 m in the western United States (Stinson, 1978; Armstrong, 1977).

The purpose of this study was to obtain values for hematocrit, hemoglobin, RBC numbers and diameter, mean cell hemoglobin, mean cell volume, and mean cell hemoglobin concentration from native populations of *Microtus* and *Peromyscus* at high and low altitude in order to: (1) assess hematological adaptation to high altitude hypoxia; and (2) test the hypothesis that semi-fossoriality results in preadaptation to high altitude hypoxia.

This study examined some phenotypic expressions of adaptation to hypoxia. If adaptations have occurred as we hypothesized, low-altitude *Microtus* should show blood characteristics that suggest greater adaptation to hypoxia than lowland *Peromyscus*. High-altitude *Peromyscus* should show such adaptations compared to lowland *Peromyscus*, but hematological values of high-altitude and lowland *Microtus* should be similar.

MATERIALS AND METHODS

Hematological values were obtained from native populations of *P. leucopus*, *M. pennsylvanicus*, and *M. ochrogaster* at an altitude of 182 m in Peoria County, Illinois, and of *P. maniculatus* and *M. montanus* at an elevation of 2900 m near the Rocky Mountain Biological Laboratory in Gunnison County,

Colorado. Animals were livetrapped from April to May 1988 in Illinois, and from July to August 1988 in Colorado. Sherman traps were baited with peanut butter-oat mixture, set at dusk, and examined at dawn the following day.

Captured animals were weighed, sexed, and marked with waterproof ink on the venter to prevent duplicate sampling in the event of recapture. Nineteen individuals of each species were sampled. Using microhematocrit capillary tubes, blood samples were taken in the field from the suborbital sinus of animals weighing 18 g or more. One hundred and fifty to 225 µl were collected per animal (two to three capillary tubes).

Blood samples were chilled, and analyzed in the laboratory within 4 hours of collection. Duplicate determinations were performed whenever possible. For the hematocrit (Hct), microcapillary tubes were spun for five minutes at 6500 rpm in a Clay-Adams microhematocrit centrifuge and measured immediately. Hemoglobin (Hb) was determined by the cyanmethemoglobin method on a Welch ChemAnal spectrophotometer set at 540 nm. Erythrocytes (RBC) were counted manually on a hemacytometer with Neubauer ruling. Premeasured diluents for cell counts or hemoglobin determinations were provided in precalibrated Unopette® diluting chambers. Erythrocyte diameter was measured on Wright's-stained dry blood smears using a Zeiss eyepiece micrometer. The diameters of fifty cells were averaged (MCD). Mean cell volume (MCV), mean cell hemoglobin (MCH), and mean cell hemoglobin concentration (MCHC) were calculated following Wintrobe (1932).

Data were analyzed by one-way ANOVA and Student's t-test, with a posteriori comparison of the means by Tukey's HSD. A two-way ANOVA was performed for altitude X genus. Minitab software was used for the analysis of variance and Student's t-test.

RESULTS

In general, hematological values for the high-altitude animals showed slightly less variability than low-altitude animals (Table 1). Among the five species studied, values for *M. pennsylvanicus* showed the greatest variability, especially in hemoglobin and consequently, the MCH calculated from it.

There were significant differences among all species in hematocrit (One-way ANOVA: $F_{4,94} = 40.09$, $P < 0.01$). Within each genus, high-altitude species had significantly greater hematocrits than their low-altitude relatives (Tukey's HSD: $q_r = 14.21, 16.63$; $q_{0.01}(5,90) = 5.66$) (Table 2). There was no difference in hematocrit between *Microtus* spp. at low altitude. Hematocrit values for *Peromyscus* were higher than *Microtus* at both altitudes, but significant differences between the genera were found only at low altitude (Tukey's HSD: $q_r = 6.26$, $q_{0.01}(5,90) = 5.66$; $q_r = 5.05$, $q_{0.01}(5,90) = 4.70$).

Analysis of hemoglobin levels by one-way ANOVA showed significant differences among all five species ($F_{4,94} = 3.89$, $P < 0.01$). Comparison of the hemoglobin levels of high- and low-altitude animals using Tukey's HSD revealed significant differences within *Peromyscus* ($q_r = 2.79$, $q_{0.05}(5,90) = 2.50$), but no significant differences within *Microtus*.

Erythrocyte numbers were significantly different among all five species (One-way ANOVA: $F_{4,94} = 4.14$, $P < 0.01$). Erythrocyte numbers did not differ significantly within *Microtus*, regardless of altitude. *Peromyscus*, however, had significantly more red blood cells at 2900 m than at low altitude (Tukey's HSD: $q_r = 2.52$, $q_{0.01}(5,90) = 1.09$). There were significant differences ($q_r = 1.73$, $q_{0.01}(5,90) = 1.09$) between *Peromyscus* and *Microtus* at high altitude, but not at low altitude. A two-way ANOVA revealed a significant interaction between genus and altitude ($F_{1,75} = 6.08, 5.42$; $P < 0.05$).

There were significant differences among all five species for MCV (One-way ANOVA: $F_{4,94} = 7.64$, $P < 0.01$). Comparison of the means by Tukey's HSD indicated significant differences within *Microtus* between highland *M. montanus* and its lowland congeners ($q_r = 10.25, 8.73$; $q_{0.01}(5,90) = 7.19$); there was no difference within *Microtus* at low altitude. Significant differences between genera were found between *M. ochrogaster* and *P. leucopus* ($q_r = 6.93$, $q_{0.05}(5,90) = 5.96$). For MCV there was a significant interaction between genus and altitude (Two-way ANOVA: $F_{1,75} = 16.44, 10.48$; $P < 0.01$).

There was no significant differences for MCH values among the five species.

Mean values for MCHC were lower among high-altitude species and resulted in significant differences among the five species (one-way ANOVA: $F_{4,94} = 9.90$, $P < 0.01$). There were significant differences between *M. montanus* and *M. ochrogaster* (Tukey's HSD: $q_r = 6.21$, $q_{0.01}(5,90) = 5.33$) and between *M. montanus* and *M. pennsylvanicus* ($q_r = 7.85$, $q_{0.01}(5,90) = 5.33$). Significant differences were found between genera at low altitude: *P. leucopus* and *M. ochrogaster* ($q_r = 4.52$, $q_{0.05}(5.90) = 4.42$) and *P. leucopus* and *M. pennsylvanicus* ($q_r = 6.16$, $q_{0.01}(5,90) = 5.33$). A significant interaction for MCHC was found (Two-way ANOVA: $F_{1,75} = 7.06, 12.26$; $P < 0.01$).

Student's t-tests were performed on MCD values; ANOVAs were not performed due to unequal sample sizes. MCD differed significantly within *Peromyscus* ($t_{1,23} = 2.81$, $P < 0.005$) and between genera at high altitude ($t_{1,36} = 2.43$, $P < 0.01$). There were no other significant differences between or within genera for mean erythrocyte diameter. MCD in *P. maniculatus* and *M. montanus* was lower in this study than in Sealander's (1964). His small sample sizes may account in part for the discrepancy.

Although MCD can give a general idea of red cell size in relation to surface area and cell volume, it is not considered an accurate index by Wintrobe (1932). An increase of 1.0 μ in diameter in a red cell represents an increase of 44% in cell volume (Haden, 1923). Furthermore, cell thickness varies more than does cell diameter (Wintrobe, 1932). Nonetheless, in this study there does seem to be a positive association between MCV and MCD when comparing genera at low altitude. At high altitude, however, this association disappears.

DISCUSSION

The results of this study demonstrated that two related rodent genera, native to high and low altitude, differ hematologically. The question was how hematological differences at different altitudes represent adaptations to hypoxia, and whether semi-fossoriality resulted in preadaptation to the hypoxia of high altitude.

Hematological values for hematocrit and hemoglobin for *M. pennsylvanicus* and *P. leucopus* were similar to those reported in the literature (Dunaway and Lewis, 1965; Sealander, 1964). In this study, the hematocrit for *P. maniculatus* was significantly greater ($t_{1,33} = 4.99$, $P < 0.01$) than that found by Sealander (1964). Hemoglobin and hematocrit for *M. montanus* (Hb = 17.2 g%, Hct = 55.6%) were higher than those found by Sealander (Hb = 14.4 g%, Hct = 46.7%; 1964) although statistical significance could not be tested with his data.

A common and generally expected response of mammals to hypoxia is an increased production of hemoglobin and RBCs. This study confirmed other reports of the increased erythropoietic activity in highland *P. maniculatus*, resulting in higher hematocrit, hemoglobin, and RBC number (Snyder, 1982; Snyder et al., 1982; Hock, 1964). However, polycythemia is not always found among highland rodents (Morrison et al., 1963 a,b; Kalabuchov, 1937) and, indeed, although possessing a higher hematocrit, *M. montanus* did not have a higher number of RBCs than its low-altitude congeners (Table 1).

The RBCs in *P. maniculatus* at high altitude were smaller, but "thicker" than those of low-altitude *leucopus*, since the cells contain the same volume within a smaller diameter (Table 1). MCH and MCHC in *Peromyscus* at high altitude were maintained, therefore, at the same level as at low altitude through an increased production of hemoglobin and RBCs (Table 1). RBCs of *M. montanus* were "thicker" than those of *Microtus* at low altitude; the larger cell volume resulted in a higher hematocrit for *montanus*. The increase in RBC volume, however, was not matched by a commensurate increase in hemoglobin production; mean cell hemoglobin concentration, therefore, was less in high-altitude voles.

At first glance, this does not appear to be an adaptation to hypoxia. A greater hemoglobin concentrating ability is expected in an animal experiencing hypoxia within a burrow (Quilliam et al., l971). Hurtado (1932), however, proposed that since hemoglobin is distributed at the inner surface of the cell membrane, the increased surface area of a cell of larger volume actually enhances oxygen loading and unloading between RBC and tissue.

It should be recognized that these rodents may respond to hypoxia using mechanisms other than those investigated here. For example, high hemoglobin-oxygen affinity (low P_{50}) is commonly found among burrowers and rodents native to high altitude, including *Peromyscus* (Snyder, 1985; Snyder, 1982; Snyder et al., 1982; Ar et al., 1977; Lechner, 1976; Baudinette, 1974; Bullard, 1972; Hall, 1966, 1965), in addition to an ability to utilize oxygen at a lower critical environmental oxygen tension (Pc) (Rosenmann and Morrison, 1985; Hall, 1966). There is evidence of hypoxic resistance in *M. pennsylvanicus*,

who experienced a smaller increase in respiratory rate under hypoxia than other lowland rodents, including *Peromyscus* (Rosenmann and Morrison, 1975).

This study demonstrated that these *Microtus* and *Peromyscus* respond differently to altitude; however, differences reflected in these seven hematological parameters provided no evidence for semi-fossorial preadaptation to altitude hypoxia. Rather, these differences probably reflect alternative ways (i.e., increased hematopoiesis in *Peromyscus* versus altered red cell volume in *Microtus*) of solving the same problem of low environmental PO_2. Our data do not however, preclude preadaptation to hypoxia in some other blood parameter(s).

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Table 1. Mean Hematological Values ± S.E.

Species	(%) Hct	(g%) Hb	(10 /mm) RBC	(u) MCV	(uug) MCH	(%) MCHC	(u) MCD	
M.o. (L)	41.4	15.3	11.3	37.9	13.7	37.3	6.0	(4)
	±1.25	±0.65	±0.57	±1.65	±0.26	±1.60	±0.00	
M.p. (L)	42.6	16.6	11.2	39.5	15.4	38.9	6.1	(2)
	±1.19	±0.97	±0.61	±1.99	±0.94	±1.60	±0.01	
P.l. (L)	47.6	15.6	10.8	44.9	14.8	32.8	6.3	(6)
	±1.32	±0.51	±0.42	±1.55	±0.76	±0.67	±0.01	
M.m. (H)	55.6	17.2	11.6	48.2	14.9	31.1	6.1	
	±1.18	±0.49	±0.31	±1.09	±0.40	±0.78	±0.05	
P.m. (H)	58.0	18.4	13.3	44.1	14.0	31.7	5.9	
	±0.95	±0.38	±0.45	±1.06	±0.38	±0.36	±0.06	

M.o. = Microtus ochrogaster, M.p. = Microtus pennsylvanicus
P.l. = Peromyscus leucopus, M.m. = Microtus montanus
P.m. = Peromyscus maniculatus
L = Low altitude (182 m), H = High altitude (2900 m)
N = 19 except as indicated in parenthesis for some MCD determinations.

Table 2. Comparisons within and between genera in Illinois (182 m) and Colorado (2900 m). Analysis with Tukey's HSD and t-test (MCD only).

Comparison	Hct	Hb	RBC	MCV	MCD	MCH	MCHC
Within Genus							
M.o. vs. M.p.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
M.o. vs. M.m.	**	n.s.	n.s.	**	n.s.	n.s.	**
M.p. vs. M.m.	**	n.s.	n.s.	**	n.s.	n.s.	**
P.m. vs. P.l.	**	**	**	n.s.	***	n.s.	n.s.
Between Genera							
M.o. vs. P.l.	**	n.s.	n.s.	*	n.s.	n.s.	*
M.p. vs. P.l.	**	n.s.	n.s.	n.s.	n.s.	n.s.	**
M.m. vs. P.m.	n.s.	n.s.	**	n.s.	**	n.s.	n.s.

M.o. = Microtus ochrogaster (IL)
M.p. = Microtus pennsylvanicus (IL)
M.m. = Microtus montanus (CO)
P.m. = Peromyscus maniculatus (CO)
P.l. = Peromyscus leucopus (IL)
* $P < 0.05$ ** $P < 0.01$ *** $P < 0.005$

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